Salmon science as related to proposed development in the Skeena River estuary

Jonathan Moore; Simon Fraser University

Charmaine Carr-Harris; Skeena Fisheries Commission

Jennifer Gordon; Lax Kw'alaams Fisheries Stewardship Program

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EXECUTIVE SUMMARY

A collaborative research team of academic and First Nation scientists has been studying the Skeena River estuary ecosystem and its juvenile salmon. After 4 years, 100 boat days, 500 net hauls, and nearly 200,000 fish sampled, this program represents the most recent extensive and in-depth research on the ecology of salmon and other fish in this ecosystem. This document provides an update on this research; it overviews past research findings as well as new results.

While the research program began prior to recent industrial development proposals, the research findings are highly relevant to understanding potential environmental risks of proposed development in the area, particularly the Pacific NorthWest LNG proposal for the Flora Bank/Lelu Island area.

Key research discoveries include:

- **The Flora Bank region contains the highest abundances of juvenile salmon compared with all other sampled habitat in the Skeena River estuary.**
- **Juvenile salmon of all species feed and grow in the Flora Bank region.**
- **Chemical tracers revealed that some juvenile salmon rear in the estuary for weeks, and some fish have chemical signatures consistent with them rearing in the region for more than a month. Overall, estuary residency varies for the different salmon species.**
- **More than 50 different locally adapted populations of Chinook and sockeye salmon use the Flora Bank ecosystem, as evidenced by genetics.**
- **Salmon that are using Flora Bank originate from the territories of at least 11 different First Nations.**
- **These salmon support dozens of commercial, recreational and Aboriginal fisheries throughout the Skeena Watershed and beyond.**
- **The Flora Bank region is used for spawning by herring and surf smelt, rearing for juvenile Dungeness crabs, and has higher abundances of juvenile steelhead than other estuary locations.**

Collectively, this science has discovered that Flora Bank is more important to young salmon and other species than assumed and assessed by the proposed Pacific NorthWest LNG project. Our findings echo research completed over four decades ago that demonstrated that the Flora Bank region is particularly important for salmon and other fishes. Previous industrial projects avoided this area because of the risks posed to the environment and natural resources like salmon. It is our scientific assessment that the proposed Pacific NorthWest LNG project, because of poor site location, poses significant risks to Skeena salmon and the fisheries that depend on them.

RESEARCH APPROACH

The North Coast Juvenile Salmon Monitoring (NCJSM) program was created to collect baseline environmental data on salmon and their ecosystem to better understand factors that affect salmon productivity during the estuary part of their life-cycle. The program has expanded to include targeted studies illuminating other aspects of the ecosystems. While this was not the original motivation, our scientific studies of the Skeena River estuary ecosystem and its fish also provide insight into the potential environmental risks of proposed projects for the region.

This research has focused on salmon because of their critical importance to fisheries, cultures, and ecosystems, but has also amassed substantial information on other components of the ecosystem, such as other fishes and environmental variables. We have now completed three years of sampling (2013, 2014, 2015) and have also included data from a similar program in 2007 led by the Skeena Fisheries Commission. This collaborative research represents a large amount of data; collectively, this body of work has consisted of more than 100 boat days, 500 net hauls, and nearly 200,000 fish sampled. To provide context for these numbers, the most up-to-date submission for the environmental assessment of Pacific NorthWest LNG (PNW LNG) reported that they have sampled a total of 35,000 fish (Stantec 2015). Our research represents the most in depth and extensive body of research on juvenile salmon and other fishes in this ecosystem to date.

One of the main priorities of the research program is to use standardized sampling of numerous different sites to gain insight into the location of key salmon habitats. We also used state-of-the-art techniques such as genetic stock identification, working with the Molecular Genetics Laboratory at Fisheries and Oceans Canada in Nanaimo, and stable isotopes, working with the University of California Davis Stable Isotope Laboratory.

Some of the research findings have been submitted and published in scientific journals in order to disseminate our findings with the broader scientific community (Carr-Harris et al. 2015, Moore et al. 2015). As part of this process, this science has been reviewed by external scientific experts and has achieved the high standard of the peer-review process. More recent aspects of our research are in preparation for publication.

This research is the product of successful collaboration among the Lax Kw'alaams Fisheries Stewardship Program, Skeena Fisheries Commission, and Simon Fraser University (Fig. 1). All fish sampling was achieved through the hard work and expertise of Lax Kw'alaams Fisheries Program personnel. Lax Kw'alaams boats and other infrastructure also underpin the field program.

Scientists from Simon Fraser University have been involved with this research program. Two graduate students from Jonathan Moore's lab at Simon Fraser University worked with the NCJSM in 2015. The estuary-fish habitat linkage project, led by Masters student Ciara Sharpe, aims to investigate how specific site characteristics, such as submerged vegetation or proximity to shore, relate to abundance of different fish species. PhD student Samantha Wilson is examining the energetics of juvenile salmon as they enter the estuary.

Fig. 1. The research team hauls in a purse seine net to collect juvenile salmon. Sampling was performed by members of the Lax Kw'alaams fisheries program and the Science Team. Photo: Tavish Campbell.

PARTICIPATION IN ONGOING ENVIRONMENTAL ASSESSMENTS

The data collected from the NCJSM project continues to inform ongoing environmental assessments of proposed developments for the Skeena River estuary. Technical advisers from the NCJSM team have participated in working groups and technical processes to evaluate the potential effects of these proposed estuary developments on salmon productivity and fisheries. For example, the NCJSM presented our results to Lax Kw'alaams community members, and to regulatory agencies including the Canadian Environmental Assessment agency (CEAA), Fisheries and Oceans Canada (DFO), Natural Resources Canada (NRCAN), and Environment Canada (EC), in a series of meetings over the last year.

The PNW LNG project is the farthest along in the environmental assessment process. This project is proposed for the Flora Bank and Lelu Island region. In this report we examine what our data means in terms of the potential risks posed by this project to key natural resources, especially salmon, and Aboriginal Rights and Title. Despite the enormous economic and cultural importance of salmon and other marine resources, there were key knowledge gaps in the initial environmental assessment of the PNW LNG project. We sought to address these data gaps to clarify potential risks.

FUNDING

Funding for this research comes from a variety of sources. Funding sources include Coast Opportunities Fund, Environment Canada, and SkeenaWild Conservation Trust; participation by Simon Fraser University scientists is supported by the Liber Ero Foundation, Mitacs, the Vanier Canada Graduate Scholarship, and the Natural Sciences and Engineering Research Council of Canada (NSERC). The Lax Kw'alaams Fisheries Stewardship Program provided substantial in-kind support through personnel and key equipment such as boats. Skeena Fisheries Commission provided in-kind support through personnel. We note that none of the funding sources had influence on the research approach or interpretation of findings.

STUDY SYSTEM

Our research program has been focusing on the Flora Bank region of the Skeena River estuary (Fig. 2) in comparison to other areas of the estuary. The North Arm of the Skeena River flows through Inverness Passage and enters the ocean at Flora Bank. Flora Bank is a shallow sandy area, approximately 2.3 km long and 1.7 km wide. This habitat is visible at low tides (Fig. 2), but at high tides it is covered by water. The majority of the eelgrass beds in the greater Skeena River estuary are located on Flora Bank (Higgins and Schouwenburg 1973, Ocean Ecology 2013). When we refer to the Flora Bank region, we are referring to the region that includes and surrounds Flora Bank itself; this region is the location of the proposed PNW LNG terminal.

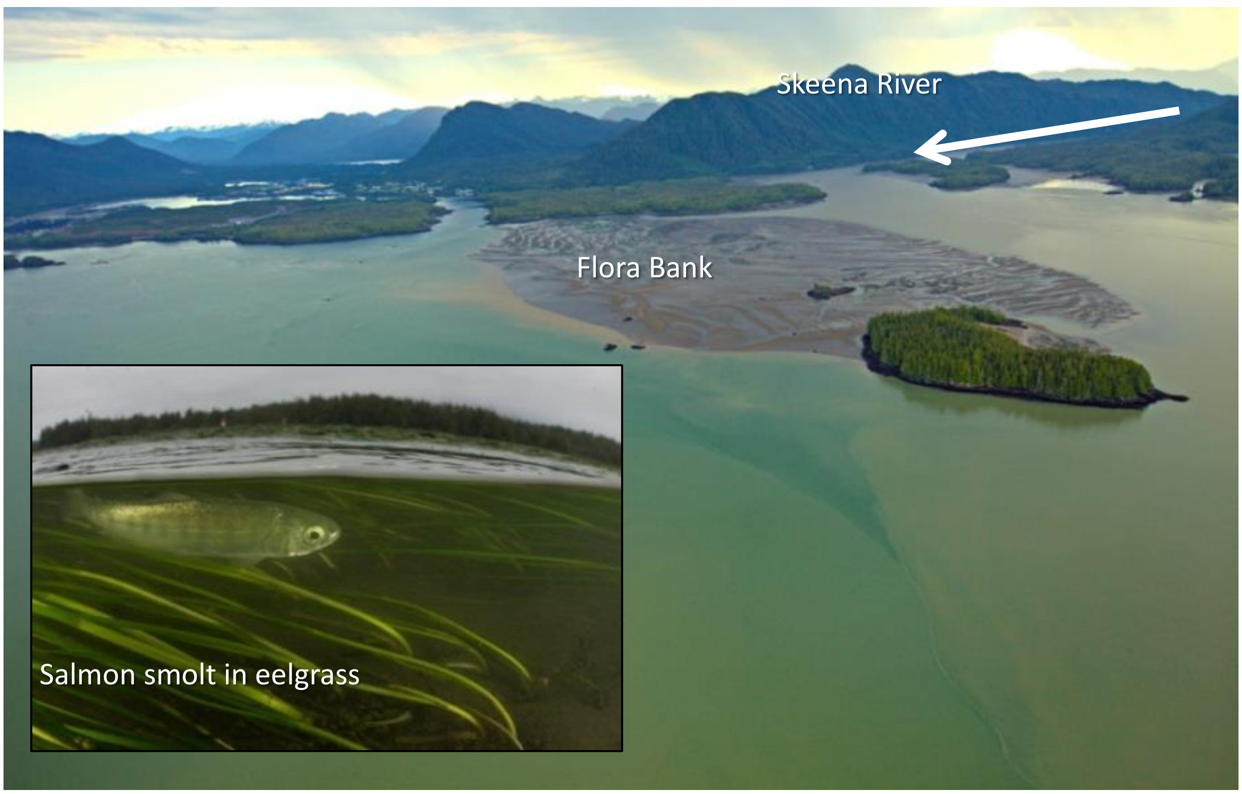


Fig. 2. Picture of the Flora Bank region of the Skeena River estuary, as seen at low tide. At high tide, Flora Bank would be under water and provide habitat for aquatic animals, such as the salmon smolt taking shelter in the eelgrass (inset picture). This is the proposed site of PNW LNG. Photos: Brian Huntington and Tavish Campbell.

SALMON AND ESTUARIES—A BRIEF BACKGROUND

Estuaries are commonly referred to as nursery habitats that provide a safe environment for the growth and development of young fish from many different species (Beck et al. 2001). However, over the last century, these estuary habitats have been degraded globally. For instance, one recent global synthesis stated that seagrass ecosystems are in a "global crisis" (Orth et al. 2006) with the total global area of seagrasses decreasing by 7% per year since 1990 (Waycott et al. 2009). The global context of this threatened ecosystem type highlights the importance of further research in the Skeena river estuary.

Estuaries are transition zones where young salmon graduate from freshwaters to the sea. All Skeena salmon must transit the estuary twice during their life cycle: as adults, when they return to freshwaters to spawn, and as juveniles, when they migrate to the sea as smolts.

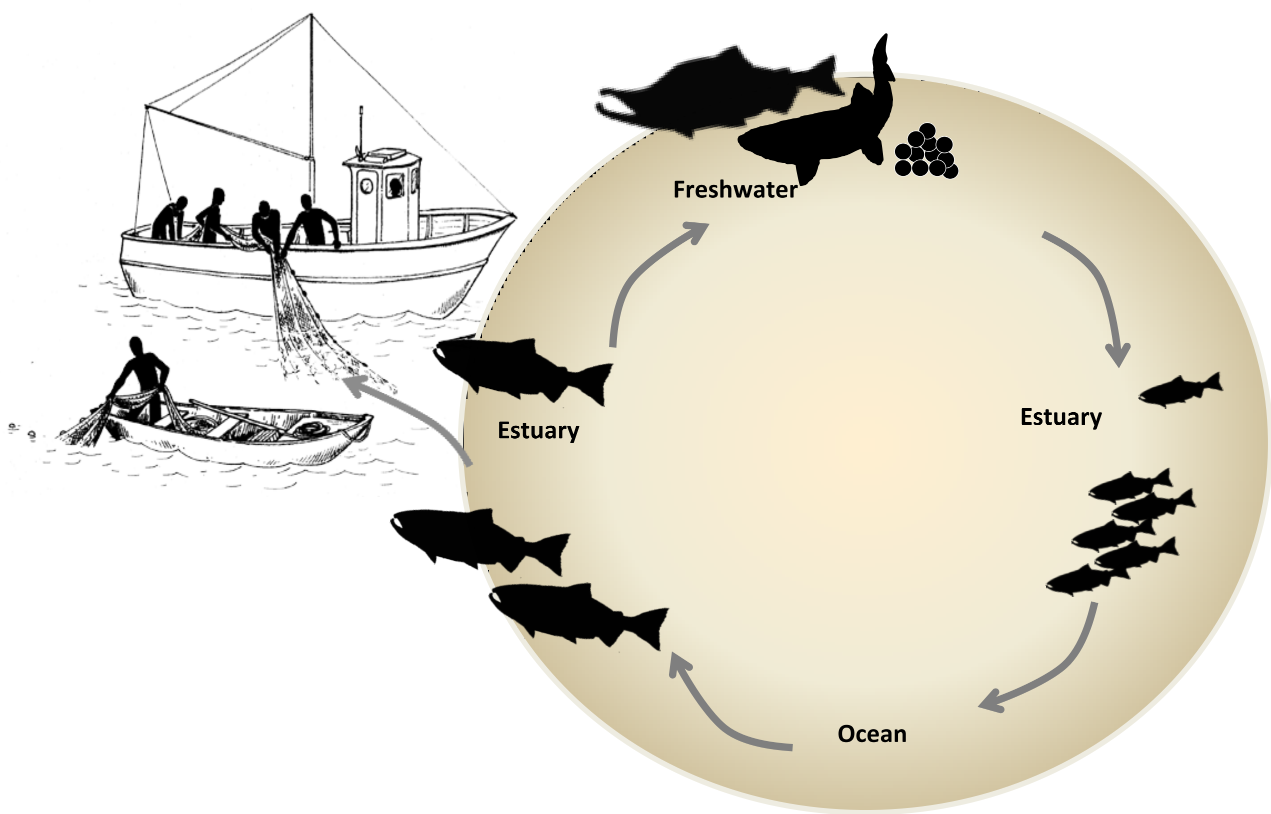


Fig. 3. The salmon life-cycle. Estuaries at the bases of large rivers like the Skeena can act as a bottleneck for their populations.

Here, juvenile salmon undergo a physiological transformation in order to tolerate saltwater, and during this time they also must eat and grow, as well as avoid being eaten by predators (Fig. 3). However, this estuarine phase of the salmon life-history is more poorly understood than other phases (Weitkamp et al. 2014) and yet is thought to be a key stage regulating population dynamics. Thus, our research can help illuminate knowledge gaps on a critical phase of the salmon life-cycle.

Estuaries provide habitat for young salmon with good feeding opportunities and protection from predators. Near-shore habitat with benthic vegetation such as eelgrass and kelp are important feeding areas, presenting unique food sources not found in other estuary habitats. For example, previous research found that chum salmon in Padilla Bay, Washington primarily feed on plankton species that are only available in eelgrass habitat (Haas et al. 2002). The estuary also acts as a refugia from predators by providing cover for young salmon with vegetation such as eelgrass and macroalgae, as well as the high turbidity (murky water) caused by high sediment carried into the estuary by the river (Macdonald et al. 1988, Semmens 2008).

Previous research has found that different salmon species tend to feed and utilize habitat in the estuary in varying ways. Generally, it is thought that coho and sockeye salmon move through the estuary in a short amount of time, while chum and some Chinook salmon will reside in the estuary for weeks or months (Weitkamp et al. 2014). Despite these differences in estuary residence time, active feeding and growth has been observed in all salmon species including those that migrate rapidly to the ocean (Weitkamp et al. 2014). There is also apparently variation within species in the degree to which certain populations use estuaries; for example, some populations of sockeye salmon reside in estuaries for extended periods of time (Simmons et al. 2013). When Chinook, pink and chum salmon migrate into the estuary, they are thought to spend this phase in the shallow near-shore environments feeding on epibenthic zooplankton such as harpacticoid copepods and epiphytic crustaceans (Naiman and Sibert 1979, Healey 1982). Juvenile coho, sockeye, and steelhead are thought to reside in deeper-water environments feeding on neritic zooplankton and small fish (Healey 1982, Simenstad et al. 1982). Productive feeding on zooplankton allows for salmon to achieve high growth rates in the nursery habitat of the estuary before migrating to the open ocean (Simenstad et al. 1982).

Juvenile salmon are a part of an estuary food web that is sustained by a variety of energy sources. Terrestrial nutrients and energy are transported downstream by rivers into the estuary (Naiman and Sibert 1979). Estuaries are also sustained by oceanic sources of nutrients and energy. Both of these sources, as well as internal cycling of nutrients from decomposition of detritus, fuel primary production that is both benthic (e.g., eelgrass and macroalgae like kelp) and pelagic (e.g., phytoplankton up in the water column) (Sigmon and Cahoon 1997). In estuaries, there are also often high rates of direct uptake of dissolved carbon by microbes. Collectively, these microbes and phytoplankton are consumed by a variety of zooplankton such as copepods (Naiman and Sibert 1979). These zooplankton, as well as some benthic invertebrates, terrestrial invertebrates, and small fishes, provide the predominant food sources for juvenile salmon. Juvenile salmon, as well as other small fish such as smelt and herring, are important food sources for other fish, birds like ospreys and murrelets, and mammals like river otters and seals (Macdonald et al. 1988, Dolloff 1993).

The growing body of research on salmon in estuaries suggests that a number of factors may influence the suitability of estuaries for juvenile salmon. One study tagged juvenile Chinook salmon with acoustic tags and tracked how they used different types of habitats in a Washington estuary (Semmens 2008). Juvenile Chinook salmon preferred to use native eelgrass habitats compared with other habitat types. Furthermore, the individuals that used the eelgrass habitat were more likely to survive than individuals that used it less. Studies have compared the survival of salmon in estuaries that have been degraded to those that are pristine and found that a greater percentage of Chinook salmon survive in systems that are more pristine (less industrial development) (Magnusson and Hilborn 2003, Meador 2014). However, much remains unknown in terms of the specific habitat attributes that define key estuary habitats for juvenile salmon as well as other estuary fishes.

In large river systems such as the Skeena River, estuaries act as physical bottlenecks for all upstream salmon populations. The Skeena River estuary drains an area the size of Switzerland, and contains dozens of salmon populations, all of which must transit the estuary on the way to the ocean. Thus, every year, hundreds of millions, and in some years perhaps even more than a billion, young salmon transit the estuary (Carr-Harris et al. 2015).

PROPOSED DEVELOPMENT

There are several large-scale industrial development projects proposed in the Flora Bank region which are currently undergoing different stages of the environmental assessment processes, including the proposed PNW LNG facility. A proposed potash loading facility on Ridley Island, has received its environmental certificate from the Canadian Environmental Assessment agency and has entered the permit application process to begin the dredge and disposal stage of the project, which will entail disposing 440,000 m^3 of (potentially contaminated) sediments in the estuary less than one kilometer off Coast Island. Environmental assessments are also underway for two additional LNG terminals, Prince Rupert LNG (PRLNG) proposed for Ridley Island, and Nexen's Aurora LNG terminal on Digby Island, for which a faster provincial environmental assessment has been substituted for a federal process. In addition, the two gas pipelines that would supply PNW and PRLNG, for which federal environmental assessments were not required, have been granted environmental certificates by the provincial government.

The PNW LNG terminal proposed for Lelu Island is considered to be the most advanced in the environmental assessment processes of all of the LNG facilities proposed for the Skeena River estuary. Construction for the proposed PNW terminal will entail dredging 790,000 m^3 of sediments and rock from Porpoise Channel to build a materials offload facility (MOF), clearing most of Lelu Island (a greenfield site) to accommodate up to three LNG trains and storage tanks, and installing a 2.2 km hybrid suspension bridge/trestle to a deep sea berth/loading facility in Chatham Sound off Agnew Bank. PNW would be supplied with natural gas by the proposed 900 km Prince Rupert Gas Transmission (PRGT) pipeline, which will come ashore on the southeast side of Lelu Island. The portion of the pipeline that occurs in the marine ecosystem would be buried in trenches excavated in the sediment in shallow nearshore areas prior to coming ashore on the southeast side of Lelu Island, and laid on top of the seabed in deep waters (from North Chatham Sound to Horsey Bank).

At the time of writing, PNW had received an environmental assessment certificate from the Province of British Columbia but has yet to complete the federal environmental assessment process, coordinated by the Canadian Environmental Assessment Agency (CEAA). Petronas has also made a positive conditional final investment decision, with a final investment decision contingent on the outcome of the federal environmental assessment.

ESTUARY FISH SAMPLING

The main objective of the North Coast Juvenile Salmon Monitoring (NCJSM) program is to collect baseline environmental data to better understand the factors that affect salmon productivity during their estuary and early marine stage of their life-cycle. This stage represents the transition point during their migration from freshwater to the ocean. Our program includes collecting physical and biological data, in addition to directly sampling juvenile salmon and other fish from nearshore and offshore estuary habitats. Here we focus on results from our estuary fish sampling activities.

From 2013 – 2015, we captured juvenile salmon and other fish species using a variety of different gear types to sample different habitats throughout the Skeena River estuary. Beach seine sampling was carried out from 2013 – 2015 to sample the nearshore fish community. Beach seining occurred weekly at shoreline sites close to proposed industrial activities near the northern entrance to the Skeena River (Fig. 2). The beach seine net was 35 m long and 3 m deep, with 4 mm mesh webbing. Each beach seine sampling event consisted of a single set, during which the seine net was deployed down-current from an anchor point on the beach using a 3 m vessel.

Trawl and purse seine sampling was carried out to sample offshore fish communities. Trawl sampling was conducted with a chartered gillnet vessel (Pacific Coast) in 2013 and 2014—for more methodological details are contained in a previous publication (Carr-Harris et al. 2015). The trawl net was deployed for a targeted duration of at least 15 min and up to 20 min for an approximate tow length of 1 km depending on the velocity of prevailing currents. All trawls were conducted within 1 km from shore over water depths ranging from approximately 5 m to over 800 m.

Purse seine sampling was carried out in 2014 and 2015 (Fig. 1). The purse seine, which was 30’ deep and 240’ long, with 2” webbing at the tow end and ½” webbing at the bunt, was deployed using a 3m skiff to tow the bunt end away from a larger vessel, and hold the net open into the tidal current for a targeted duration of 5 minutes per set. At the end of each set, the purse seine was closed and bagged by simultaneously pulling a purse line while hauling the web into the larger vessel. Once the net was closed, fish were transferred from the seine net into buckets using dip nets. For all gear types (beach seine, purse seine, and trawl), captured fish were counted to species and all non-salmonids were released after each beach or purse seine set. Salmon were counted to species, and length data were collected from up to 50 individuals of each species per set. A smaller number of salmon specimens were retained for further biological analyses, which are described in subsequent sections of this report.

TEMPORAL DISTRIBUTION OF JUVENILE SALMON

The results from the NCJSM fish sampling program indicate that the Skeena River estuary supports diverse and abundant populations of juvenile salmon. During our three years of sampling, we found that the different species of juvenile salmon occupied the estuary from the middle of May until at least the end of our sampling period in the middle of July.

Key finding: Juveniles of all species of North American salmon and steelhead use the Flora Bank region of the Skeena River estuary throughout the spring and into summer.

Different species of juvenile salmon use Skeena River estuary habitats differently during the smolt outmigration period. While temporal patterns of abundance varied by species of salmon captured in the Skeena River estuary, overall patterns of abundance for all species were consistent for our three years of sampling. High abundances of juvenile pink salmon were observed during early-season beach seine sets, and were captured in diminishing abundance from the middle of April until the middle of May in all years. While the highest abundances of juvenile chum salmon were captured by beach seine from the end of April until the beginning of May in all years, smaller numbers of juvenile chum salmon were captured into June in all years. Juvenile coho salmon were captured in high abundances by beach seine, purse seine and trawl from the middle of May onward. Juvenile Chinook salmon were captured primarily by purse seine and trawl from the middle of May onward in all years, with higher abundances observed in 2014 compared with 2013 and 2015.

Juvenile sockeye salmon, which were also mostly captured by trawl and purse seine, were the most abundant salmon species captured by offshore gear types (trawl and purse seine) in all years. Sockeye salmon were continually present in the study area from early May until the end of sampling in mid-July, with peak abundances observed between the last week of May and the first week of June in all years. The lowest abundances of juvenile sockeye salmon were observed in 2015, which was not surprising following exceptionally low sockeye salmon returns to the Skeena River in 2013, the dominant brood year for the sockeye salmon smolts that we observed in the estuary in 2015.

SIZE OF JUVENILE SALMON

We have collected length data from more than 9,000 fish, including 1,956 sockeye salmon, 167 Chinook salmon, 1,174 coho salmon, 1,568 pink salmon, and 361 chum salmon since 2013. The individual length of all salmon species increased throughout the sampling period in all years. The lengths of juvenile pink and chum salmon, which enter the estuary immediately after emergence, increased more rapidly than sockeye or coho salmon. For example, in 2015, the mean length of pink salmon increased by 0.95 + 0.02 mm/day ($P < 0.0001$) between March 23 and July 8, doubling in length in less than two months, while the mean length of coho salmon increased by 0.25 + 0.05 mm/day ($P < 0.0001$) during the same time period (Fig. 4).

Key finding: Juvenile salmon sizes are bigger throughout the spring/summer, evidence that they are growing in the estuary.

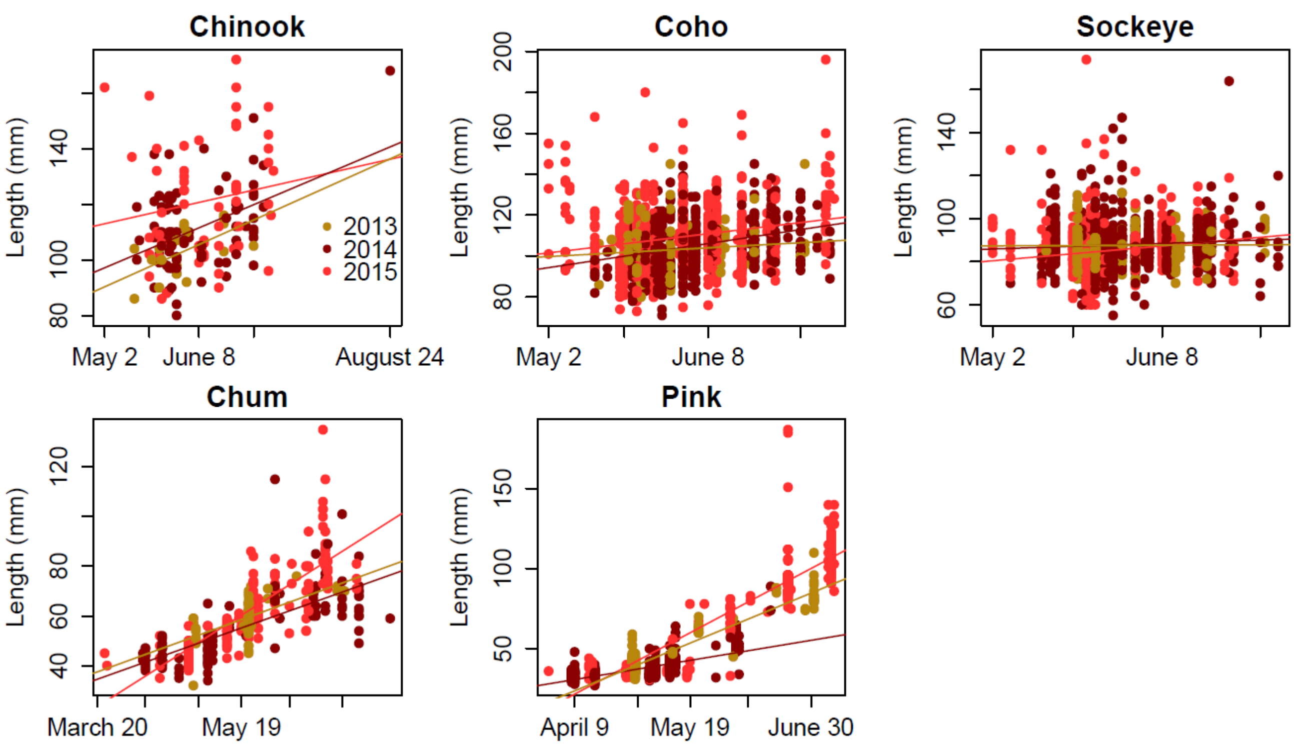


Fig. 4. Lengths for juvenile Chinook, coho, sockeye, chum and pink salmon captured from 2013 – 2015. Corresponding regression lines showing positive linear relationships are shown for each year.

The size distribution of juvenile salmon in the estuary will be controlled by the growth of individuals within the estuary, as well as the arrival of new smolts to the estuary. A positive relationship between time and size supports the hypothesis that fish are rearing and growing in the estuary. While juvenile salmon might enter the estuary at different sizes or at different times, this would generally only obscure the relationship between size and time.

ESTUARINE FISH COMMUNITY

While juvenile salmon ecology is the principal focus of the NCJSM program, our sampling platform has provided an opportunity to collect data for many other fish species that occupy estuary habitats (Fig. 5). Some of these other fish species feed on juvenile salmon during the period of estuary residence, while others provide food for them. Some, such as Pacific herring (*Clupea pallasi*) are culturally and economically important species which are harvested in commercial or Section 35 fisheries. We captured more than a dozen other fish species, including Pacific herring, surf smelt (*Hypomesus pretiosus*), sand lance (Ammyotidae), longfin smelt (*Sprinchus thalichthys*), surfperches (Embiotocidae), Pacific sandfish (*Trichodon trichodon*), threespine stickleback (*Gasterosteus aculeatus*), starry flounder (*Platichthys stellatus*) and various other species of flatfishes and sculpin. Pacific herring and surf smelt were the most abundant of all fish species captured by beach seine, purse seine, and trawl sampling in all years.

We captured mature adult herring and surf smelt throughout the 2015 sampling period, including spawning aggregations of surf smelt which were captured off Kitson Island in the middle of June, at the same location in both 2013 and 2014, suggesting that the nearby intertidal area is an important spawning beach for these animals. We captured a spawning aggregation of herring on Flora Bank in the middle of June, and observed herring eggs deposited on eelgrass on Flora Bank two weeks later. This may represent a unique spawning population of herring, based on the timing of egg deposition, which is more than two months later than other North Coast herring populations.

Key finding: The Flora Bank region is used for spawning by herring and surf smelt, rearing for juvenile Dungeness crabs, and has higher abundances of juvenile steelhead than other estuary locations.

Invertebrate species were not specifically targeted during the NCJSM sampling project, however we captured numerous juvenile and adult Dungeness crabs in beach and purse seine sampling. This is evidence that Dungeness crabs, an important species for fisheries, are using this habitat throughout their life-cycle, including as nursery habitat.

We also collected a handful of juvenile steelhead (anadromous *Oncorhynchus mykiss*) (N = 12) across years and sampling efforts. Steelhead were not caught in beach seines, but were occasionally caught in purse and trawl sampling. Half of the these juvenile steelhead collected by purse/trawl sampling were collected at Flora Bank/Inverness (50%) compared to all other sites, even though relatively few sets were performed in this region compared to all others (19%). Even though sample sizes are low, this difference is unlikely to have happened by chance; there is only a 2% chance that this pattern occurs randomly.

Fig. 5. Some of the common fish species in the Skeena estuary that are not juvenile salmon, such as herring, perch, and smelt.

REGIONAL ABUNDANCE PATTERNS OF SALMON

We analyzed trawl sample data collected during the NCJSM program in 2013 and by Skeena Fisheries Commission in 2007 to investigate the spatial distribution of different species of juvenile salmon throughout the Skeena River estuary. Trawl sites throughout the estuary were aggregated into broad regions according to their relative proximity to the northern or southern exit of the Skeena River (Fig. 6). The 2007 trawl sampling program encompassed five regions (Inside North (IN), Outside North (ON), Middle (MID), Inside South (IS), and Outside South (OS)), and the 2013 program encompassed three of the five regions that were sampled in 2007 (IN, IS, and OS) (Fig. 6). The IN region contains several proposed development footprints including the proposed PNW and PRG LNG terminals

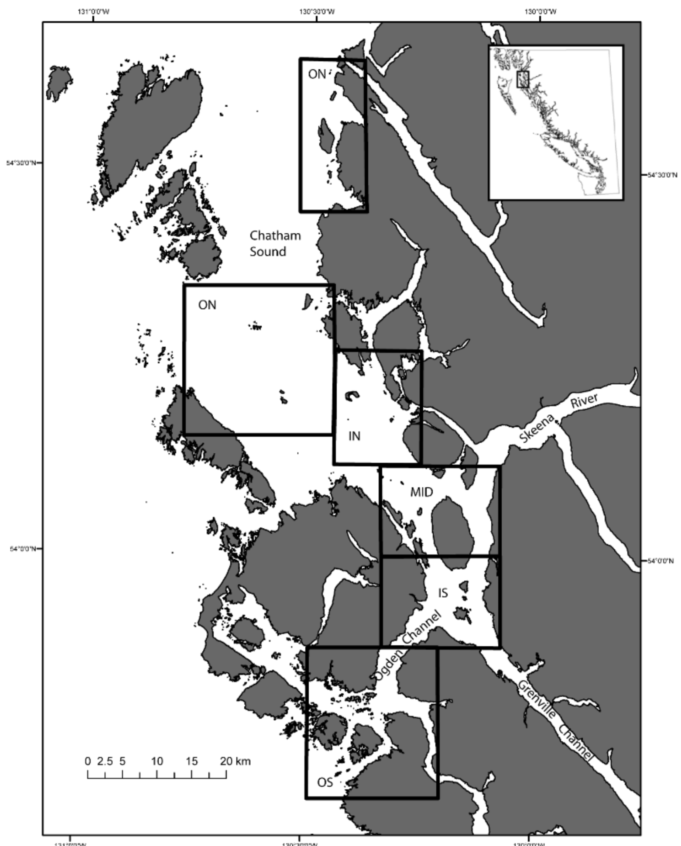


Fig. 6. The Skeena River estuary and distribution of juvenile salmon sampling. During the period of highest flow, the zone of freshwater influence extends from the mouth of the Skeena River south to Ogden and Grenville Channels, and northwest through Chatham Sound, which also receives freshwater from the Nass River. The study area is shown divided into our analysis regions indicated by the letters IN for inside North, ON for outside north, MID for middle, IS for inside south, and OS for outside south. Note that the ON region includes two polygons. From (Carr-Harris et al. 2015)

We analyzed trawl catch-per-unit-effort (CPUE) for sockeye, coho and Chinook salmon with generalized additive models (GAM) to compare abundances across regions. The GAMs predicted the mean CPUE for each species by region for each year with a model of the form:

$$Y = f(d) + \beta(x)$$

where *Y* is the CPUE (mean normalized catch per 20 min set) for a given species, *f* is a smooth function (thin-plate regression spline) for day of year *d*, and the β coefficient is the mean abundance for each region *x*. In other words, these models examine the relative effect of each region on catch rate, after controlling for time. We ran a separate model for each species and each year using a negative binomial distribution with a log link. β is thus an estimate of the relative CPUE of each region on day 0, and is on a log-scale. We used the fitted models to predict the relative abundances of each species at regular intervals in each region during the sampling period, which were back transformed to produce estimates of the CPUE at each region for each prediction interval.

Key finding: The Flora Bank region has approximately twice as many young coho, Chinook, and sockeye salmon compared with other regions in the estuary.

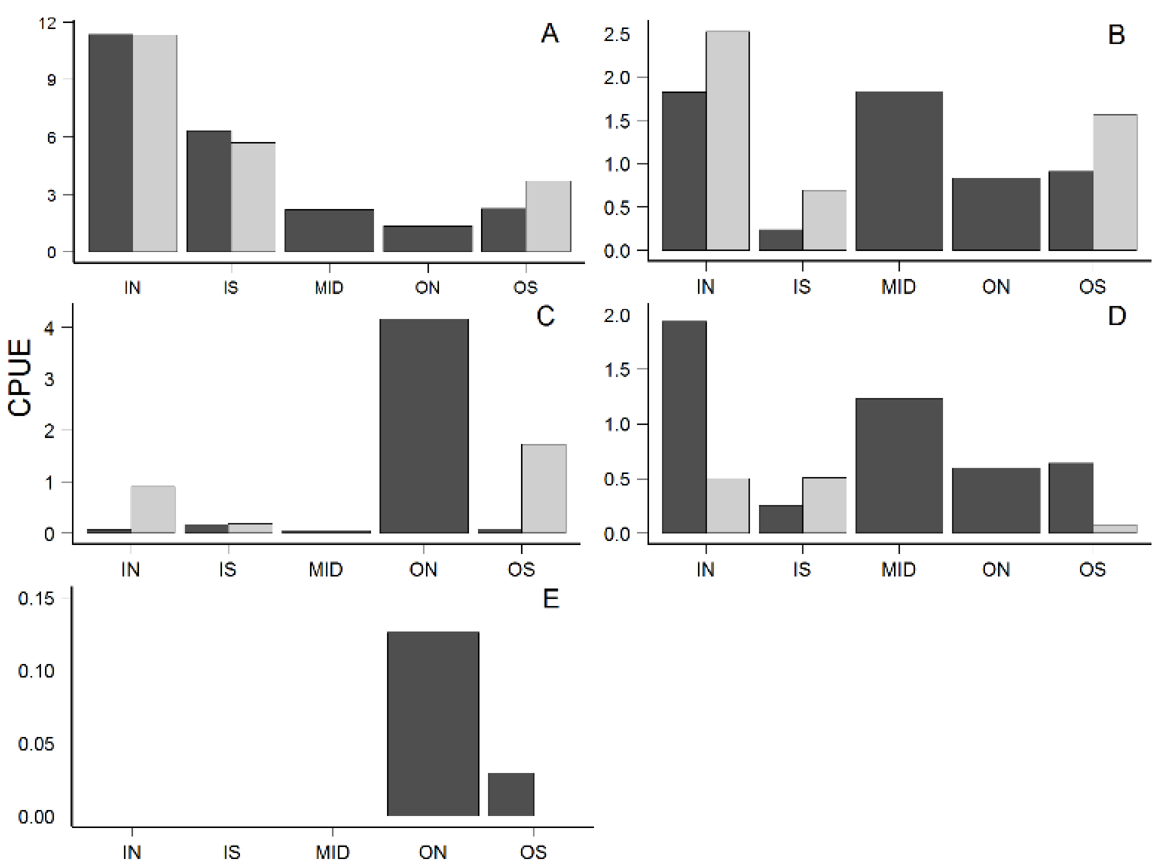


Fig. 7. Average normalized trawl catch of all species of juvenile sockeye (a), coho (b), pink (c), Chinook (d) and chum (e) salmon, pooled across all locations and sampling dates and normalized for 20 min sets. Dark grey bars indicate 2007 and light grey bars indicate 2013. Note different scales for y-axes for different species. From (Carr-Harris et al. 2015).

We observed the highest densities of some species of juvenile salmon, including the highest densities of juvenile sockeye salmon in both years, juvenile coho salmon in 2013, and juvenile Chinook salmon in 2007 (Fig. 7) in the IN region. Generalized additive modeling statistically indicated that juvenile sockeye salmon were most abundant in the IN region in both years, and juvenile coho salmon were most abundant in the IN region in 2013 (Fig. 8). The β coefficient for sockeye in the IN region was 1.74 $\pm$ 0.36 ($p < 0.0001$, this and the following represent the best estimate of the coefficient $\pm$ 1 SE and P-value of the coefficient) in 2007 and 1.56 $\pm$ 0.34 ($p < 0.0001$) in 2013 (Fig. 8). The predicted abundances for sockeye salmon in the IN region were 2-8 x higher than in the other regions in both years. The β coefficients for coho salmon in the IN region were 0.63 $\pm$ 0.28 ($p = 0.0262$) in 2007 and 0.45 $\pm$ 0.19 ($p = 0.022$) in 2013 (Fig. 8); thus predicted abundances for coho salmon were 2-7 x higher in the IN than in other regions in 2013, and 2-7 x higher in the IN and MID regions than in other regions in 2007. Chinook salmon appeared to be most abundant in the IN region in 2007 and in the IS region in

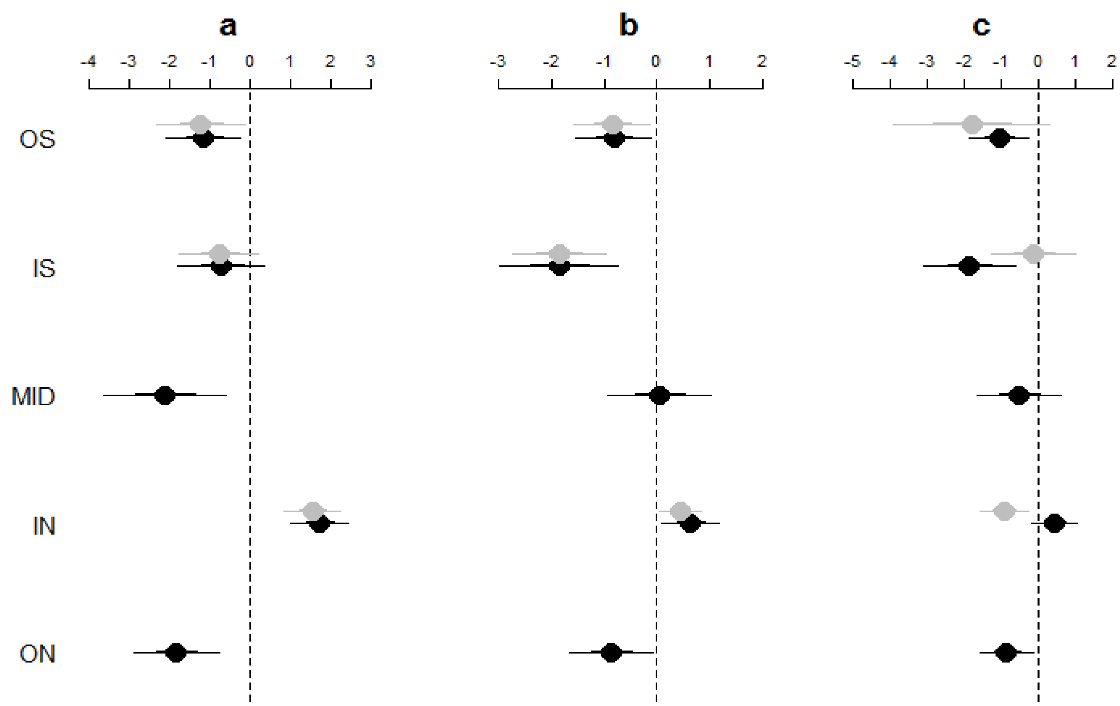


Fig. 8. GAM coefficients for parametric region covariates for sockeye (a), coho (b) and Chinook (c) salmon. Coefficients are related to the (log) mean normalized catch per trawl set for each region in 2007 (black) and 2013 (grey). Thus, a value of 0 indicates a mean normalized trawl catch of 1. Error bars indicate $\pm$ 2 standard errors. From (Carr-Harris et al. 2015).

2013, however neither of these values were significant ($p > 0.05$).

Abundances of sockeye and coho salmon were consistently higher in the IN region compared with other regions in the two years sampled, suggesting that this region contains important rearing areas for out-migrating salmon smolts. These data provide evidence that while the Skeena River estuary in general contains high abundances and diversity of juvenile salmon, the area proposed for development contains some of the highest densities of the most ecologically and economically important species of Skeena River salmon. The results from this study have been peer-reviewed and published (Carr-Harris et al. 2015).

LOCAL ABUNDANCE PATTERNS OF SALMON

In 2015, we investigated the usage of different habitats by salmon at a more local scale. Using standardized sampling, we compared the abundance of salmon during the spring-summer season at 25 sites that ranged from Inverness to the shoulders of Flora Bank to Digby Island and the mouth of Prince Rupert Harbor (Fig. 9). Sites were selected to represent different habitat types, such as eelgrass habitats and off-shore habitats. Each site was sampled repeatedly during late spring/early summer. These data were collected to understand whether different locations of the greater Skeena River estuary support more juvenile salmon than other locations.

Captured fish were identified to species, counted, and all non-salmonids were released after each set. A subsample of salmon, herring, and surf smelt from each sampling event (up to 50 individuals of each species) were lightly anesthetized with MS-222, and their lengths recorded to the nearest mm. These fish were released following a recovery period in aerated buckets. A smaller subset of juvenile sockeye salmon was sacrificed for bioenergetics analyses (see below). Fin clips were collected for genetic analyses on a subset of fish (see below). We focused on juvenile coho salmon, sockeye

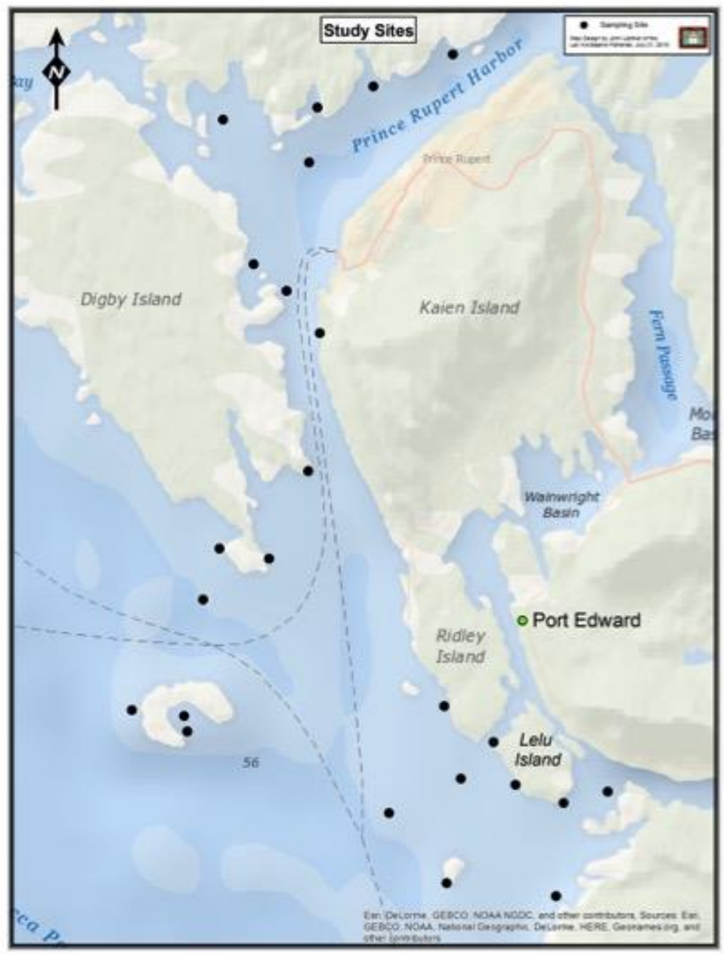


Fig. 9. Sites for the 2015 purse seine study of juvenile salmon in the Skeena River estuary. Dots show sampling sites; sites were sampled repeatedly during late spring/early summer. Map created by John Latimer of Lax Kw'alaams Fisheries Stewardship Program.

salmon, and Chinook salmon because pink and chum salmon appear to reach peak abundances in the estuary earlier than we sampled and often are found in shallow nearshore habitats that were not sampled as effectively by our deep purse seine.

We grouped the 25 sites into eight sub-regions. We compared the abundances of juvenile salmon at the Flora Bank sub-region with their abundances at other sub-regions. Juvenile coho, Chinook, and sockeye salmon were many-times more abundant in the Flora Bank sites than any of the other sub-regions (Fig. 10). Flora Bank sites even had more salmon than sites that were farther south (closer to mouth of the Skeena River) (Fig. 10).

- Coho salmon were 9 times more abundant in Flora Bank compared with the other sub-regions, on average.
- Chinook salmon were 3.5 times more abundant in Flora Bank compared with the other sub-regions, on average.
- Sockeye salmon were 37 times more abundant on Flora Bank compared with the other sub-regions, on average.

These data provide more resolution on the abundance patterns of juvenile salmon than our previous research (Carr-Harris et al. 2015). We consistently have found that the Flora Bank area has particularly high abundances of the three juvenile salmon species that are most important for fisheries.

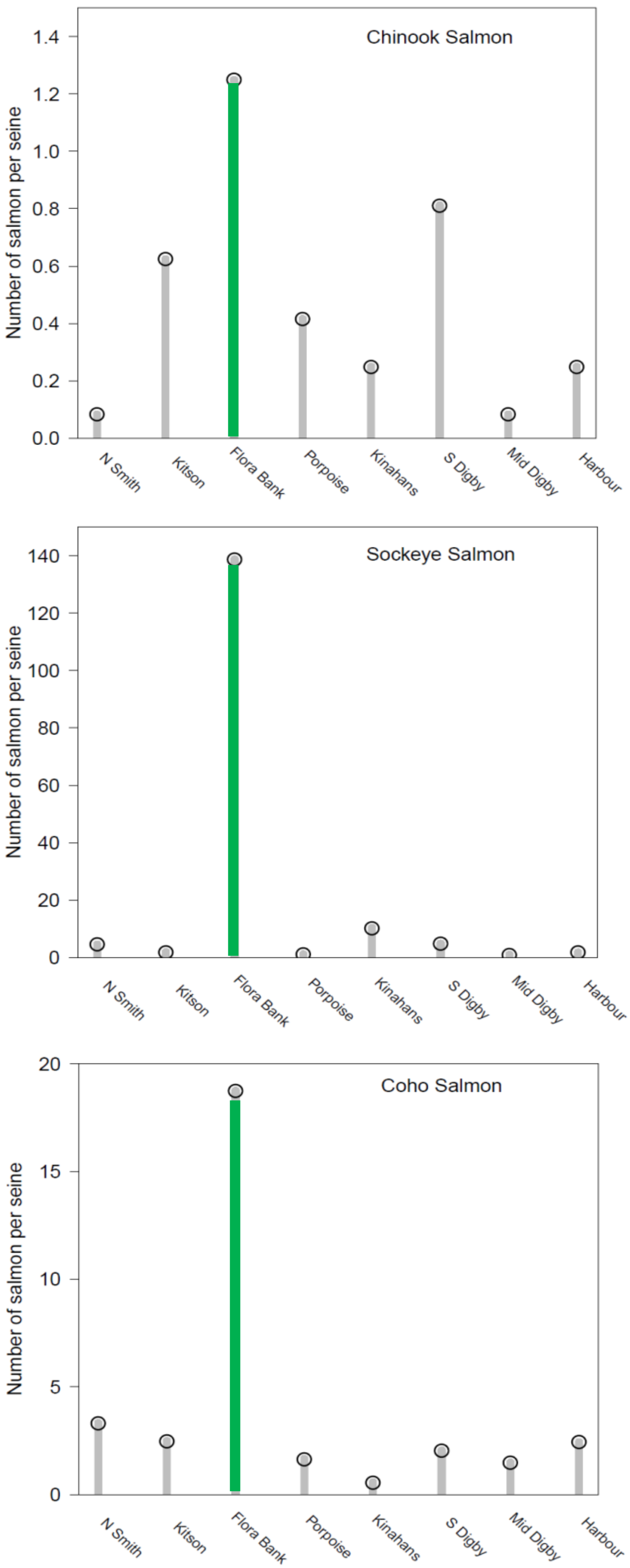


Fig. 10. Relative abundance of juvenile salmon captured by purse seine. Shown are the average number of juvenile salmon of the different species caught in a single purse seine set. Sites are grouped into the following categories with the following numbers of sites: North Smith (3 sites), Kitson (2), Flora Bank (2), Porpoise Channel (3), Kinahans (3), South Digby (4), Middle Digby (3), and Prince Rupert Harbour (5). Categories are ordered from south (left) to north (right). Flora Bank sites are emphasized with green colour.

These data also allowed us to control for habitat type and see if different locations with the same habitat type have comparable salmon densities. For example, the Environmental Assessment of the proponent implicitly assumes that salmon use eelgrass habitats similarly throughout the Skeena River estuary, and that loss of Flora Bank eelgrass habitats caused by project construction can be mitigated, or offset, by planting eelgrass elsewhere. We compared the abundances of juvenile salmon in eelgrass sites in the Flora Bank sites compared to other eelgrass sites. Sites were designated as being “eelgrass sites” if they were on or near eelgrass. We compared two eelgrass sites at Flora Bank with three eelgrass sites farther north. Even after restricting our analyses to only eelgrass sites, Flora Bank contained many more salmon than the other sites (Fig. 11). Specifically:

- Coho salmon were 16 times more abundant at Flora Bank sites compared with the other eelgrass sites, on average.
- Chinook salmon were 15 times more abundant at Flora Bank sites compared with the other eelgrass sites, on average.
- Sockeye salmon were 72 times more abundant at Flora Bank sites compared with the other eelgrass sites, on average.

These data reveal that Flora Bank eelgrass sites are used dramatically more than other eelgrass areas in the Skeena River estuary by juvenile salmon. This data does not mean that other eelgrass habitats are not important for some species at some time periods; however, it provides striking evidence that the Flora Bank eelgrass habitats are of particular importance. These data are relevant to the mitigation plans of the proponent—where eelgrass on Flora Bank would be destroyed and compensated by attempting to create eelgrass beds elsewhere—our data suggests that the Flora Bank eelgrass habitat for salmon would be difficult, if not impossible, to replace.

Key finding: Eelgrass habitat in Flora Bank has >20 times more salmon in general than other eelgrass habitats in the Skeena River estuary. Specifically, there were 16, 15, and 72 times more coho, Chinook, and sockeye salmon at Flora Bank eelgrass habitats compared to other eelgrass habitats.

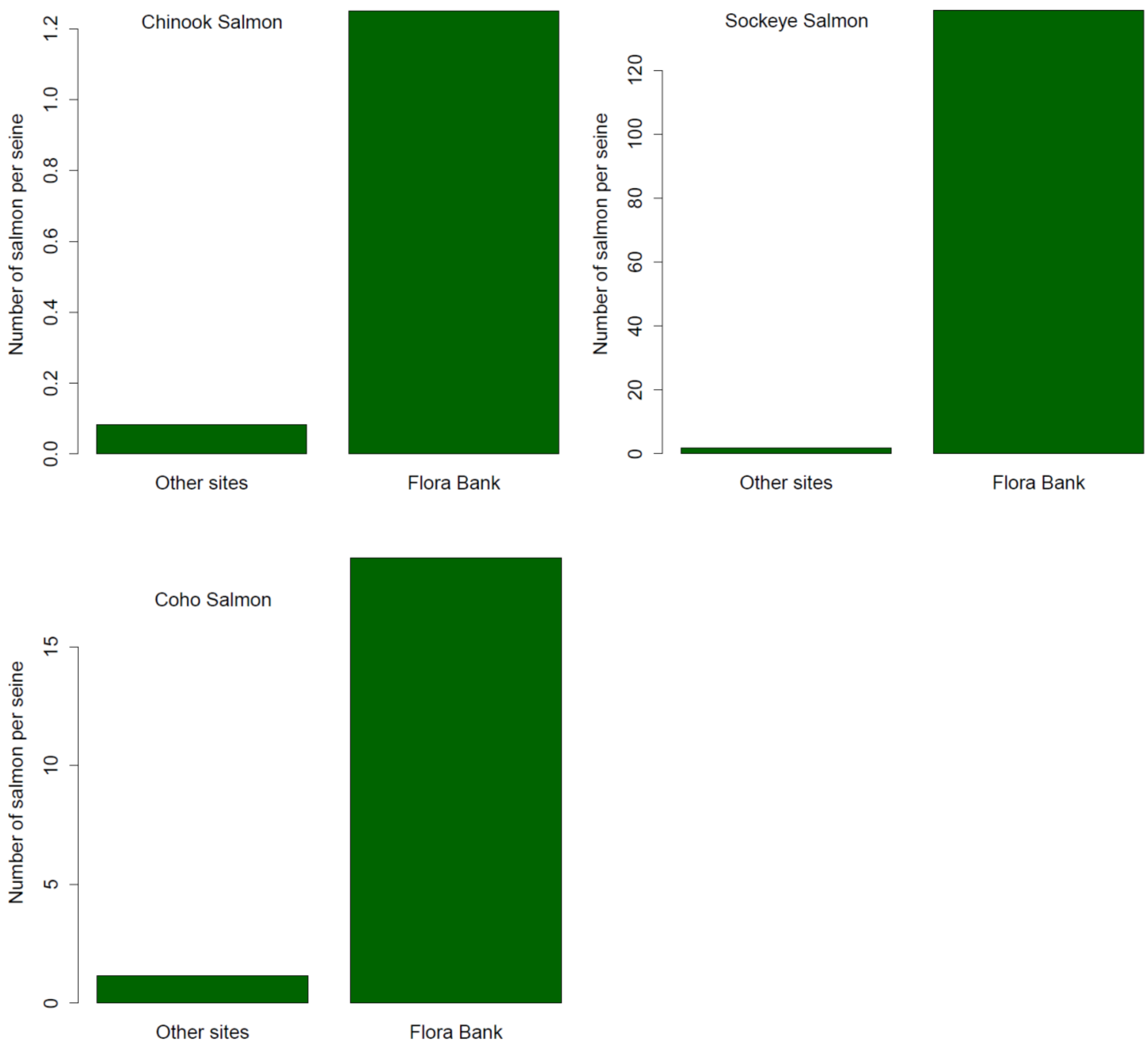


Fig. 11. Relative abundance of juvenile salmon species in “eelgrass sites”. Shown is the average catch per seine set over the sampling season. There were two eelgrass sites in Flora Bank, and three eelgrass sites farther north in the greater Skeena River estuary.

SALMON RESIDENCE IN THE ESTUARY

In order to learn about the degree to which juvenile salmon are feeding and residing in the Skeena River estuary, we used stable isotopes. Stable isotopes are naturally occurring varieties of elements that have an extra neutron, so are slightly heavier. The ratio of the heavier isotope to the lighter isotope can be measured accurately, and thereby provides a natural chemical tracer that is passed up the food chain. This project was predominantly performed during the outmigration season of 2014.

Stable isotopes can also be used to understand how animals move across habitats, such as young salmon moving into the marine ecosystem (Kline Jr and Willette 2002, Kline et al. 2008). Furthermore, the delay in their incorporation into tissues can be used as a clock to time movements across ecosystems, like the movement of salmon from freshwater to estuaries.

In order to use stable isotopes to illuminate how juvenile salmon use the estuary, we collected three main types of samples. First, we collected stable isotopes from juvenile salmon in the estuary. Second, we collected stable isotopes of juvenile salmon from their freshwater rearing grounds to describe the chemical signature of where they were coming from (the "freshwater baseline"). Third, we collected stable isotopes of fish that reside in the estuary to characterize the chemical signature of this food web (the "estuary baseline"). By comparing chemical signatures of juvenile salmon captured in the estuary to the chemical signatures of freshwater (where they came from) to the estuary (where they were caught), we can characterize the degree to which salmon are residing and feeding in the estuary.

Whenever possible, we collected both liver and muscle tissue from each fish. Liver tissue turns over extremely rapidly, on the order of days, while muscle tissue turns over more slowly, on the order of weeks. If fish were too small, we aggregated tissue samples from multiple individuals to generated pooled estimates. The these slow- and fast-turnover tissues provide different timeframes of inference for their use as clocks (see below).

For the purposes of this report, we focus on fish captured in the region around Flora Bank. This includes fish collected from sites at Agnew Bank, Kitson Island, Flora Bank, Porpoise

Channel, and Lelu Island. We used adult surf smelt (*Hypomesus pretiosus*), a zooplanktivorous estuary fish, as our estuary baseline. Freshwater baselines for each salmon species were collected by collecting salmon parr/smolts (Chinook, coho, and sockeye salmon) and fry (chum and pink) from rearing habitats in the Skeena River watershed. These freshwater baseline samples were collected by upriver First Nation fisheries programs—their collaboration and support is immensely appreciated. At least five samples were collected for each baseline. We collected pink, chum, sockeye, coho, and Chinook salmon juveniles from Flora Bank. Samples were frozen and then freeze-dried prior to shipping them for analyses.

Stable isotope analyses were analyzed by mass-spectrometry at the Stable Isotope Laboratory at University of California Davis. Samples were run for Carbon ($\delta^{13}C$), Nitrogen ($\delta^{15}N$), and Sulfur ($\delta^{34}S$). Carbon (C) and sulfur (S) are often used as tracers for habitat type, while nitrogen (N) is used as an indicator of trophic position, although many factors can influence isotope values. All samples are run against standards; values are shown as differences from these standards. Sulfur isotope analyses were not completed by the UC Davis laboratory at the time of the writing of this report; these results thus focus on carbon and nitrogen.

We estimated the timing of ocean entry using stable isotope clocks. Specifically, we estimated the time since estuary entry (t_{est}) as:

$$t_{est} = -\tau * ln\left(\frac{\delta X_{estuary} - \delta X_t}{\delta X_{estuary} - \delta X_{freshwater}}\right),$$

based on the tissue-specific isotopic turnover rate (τ) and the isotopic baseline from the freshwater ($\delta X_{freshwater}$) and estuary ecosystems ($\delta X_{estuary}$) as well as the isotope signature of the juvenile salmon collected in the estuary (δX_t).

Turnover (τ) of liver of juvenile salmonids has previously been estimated as 12.3 $\pm$ 1.5 days and muscle was 39 $\pm$ 3.2 (mean $\pm$ 1 SE) days based laboratory experiments and single compartment isotope turnover models (Heady and Moore 2013). These estimates were used in the above equation.

In order to propagate uncertainty and variability in in the calculation of time since estuary entry, we bootstrapped the following parameters: τ, $\delta X_{estuary}$, and $\delta X_{freshwater}$. We assumed normally distributed variability, and drew 1000 samples from parameter distribution. To illustrate the use of these clocks, this bootstrapping was applied to Chinook salmon, using their muscle tissues and C data—when the Sulfur isotope data are complete, all tissues and isotopes will be run and joint posterior probabilities will be calculated.

Freshwater baseline isotope signatures were different from estuary baseline isotope signatures among all the different salmon species. Estuary fish were more enriched in $\delta^{13}C$. In contrast, stable isotopes of juvenile salmon in their freshwater phase were more depleted in $\delta^{13}C$. This difference between freshwater and estuary isotope baselines enables us to distinguish between freshwater- and estuarine-derived tissues (Fig. 12). There were less systematic differences between freshwater and estuary baselines for $\delta^{15}N$.

Isotopes of juvenile Chinook salmon collected in the estuary were spread out between their freshwater baseline and the estuary baseline. Individuals that had isotopic signatures that were close to the freshwater baseline likely entered the estuary recently prior to capture. Other estuarine juvenile Chinook salmon had isotope signatures that appeared to be fully estuarine-derived. These individuals had likely been eating and rearing in the estuary for longer, allowing their tissues to become almost fully derived from estuary resources.

The isotope signatures of sockeye salmon smolts from the estuary were more freshwater in origin than those of Chinook salmon. These data illustrate that most of the sockeye salmon caught had likely entered the estuary recently. Some individuals had isotope signatures that were shifted towards the estuarine baseline—these individuals had been rearing and feeding in the estuary, likely for days to weeks. These results support previous findings from the Skeena estuary (Higgins and Schouwenburg 1973), showing that juvenile sockeye salmon migrate through estuaries fairly rapidly, but also illustrates that some sockeye salmon smolts are rearing and feeding in the Skeena River estuary. For instance, research from the Alaska peninsula has found that juvenile sockeye salmon may rear in estuaries for up to three months (Simmons et al. 2013).

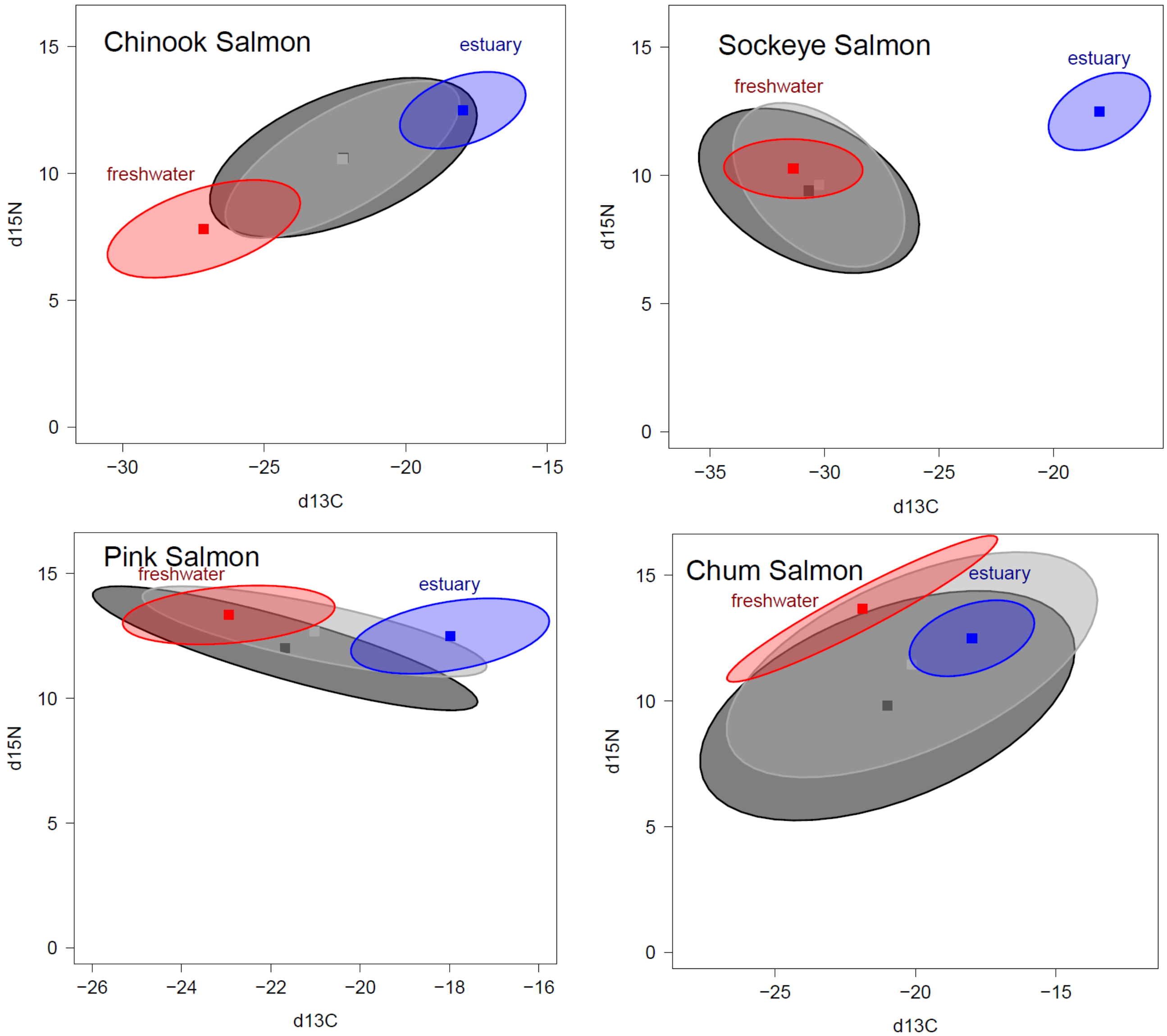
Pink salmon showed high individual variation in their isotope signatures. Some estuary-collected individuals had isotope signatures that matched the freshwater baseline, evidence that they recently entered the estuary. Other individuals had isotope signatures that were close to the estuary baseline, evidence that they had been feeding and growing in the estuary for some time. Perhaps not surprisingly, the freshwater baseline of pink salmon was characterized by isotope signatures that are typically of marine ecosystems. Because pink fry migrate immediately down to the estuary prior to extensive feeding in fresh water, freshwater pink fry have an oceanic isotopic signature that is derived from their mother. This creates less differentiation between freshwater and estuary baselines for this species.

Chum salmon had somewhat similar isotope patterns as pink salmon, with high variation in isotope signatures. These data are evidence that that some juvenile chum salmon are residing and feeding in the estuary for an extended period of time. Similar to pink salmon, chum salmon baselines were not strongly differentiated between estuary and freshwater habitats. As chum fry leave the freshwater habitat immediately upon emergence similar to pink salmon, the chum freshwater baseline had a “marine” isotope signature.

Coho salmon smolts had isotope signatures that were roughly similar to Chinook salmon, with individual isotope signatures that ranged from freshwater to estuarine.

Collectively, these data provide several key insights into juvenile salmon and their usage of the estuary. First, for all species of juvenile salmon, individuals showed evidence of feeding and rearing in the estuary. These fish are not simply swimming through the region, they are feeding actively. Second, these data provide estimates of the amount of time that individual salmon are rearing in the estuary. For example, running isotopic clocks on Chinook salmon reveals that many individuals entered the estuary weeks to months prior to their collection (Fig. 13). Furthermore, larger individuals had entered the estuary earlier—this is strong evidence that these individuals are growing substantially in the estuary.

Key finding: Juvenile salmon are feeding and rearing in the estuary for upwards of weeks to months.



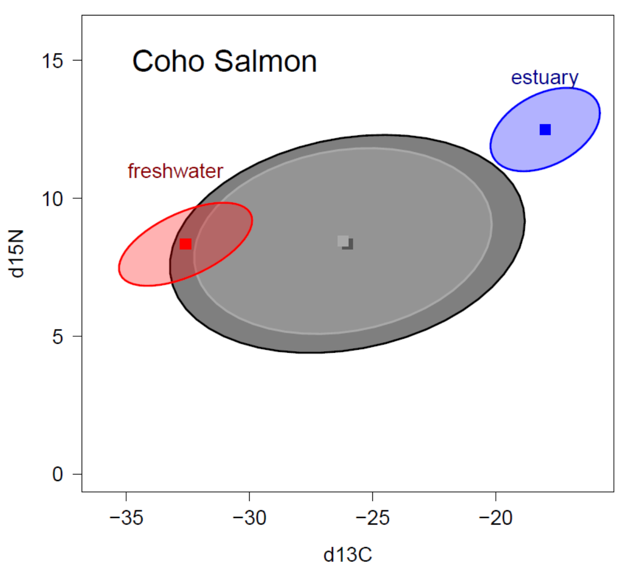


Fig. 12. Stable isotopes of juvenile salmon in the Flora Bank region of the Skeena River estuary and their freshwater and estuary baselines. Shown are 90% confidence ellipses; in other words, 9 out of 10 data points should occur within this region. The black-lined ellipse that is darker gray represents isotope values of liver tissues, while the lighter gray ellipse represents muscle tissues. Different panels show different species of salmon that were sampled as juveniles in the estuary.

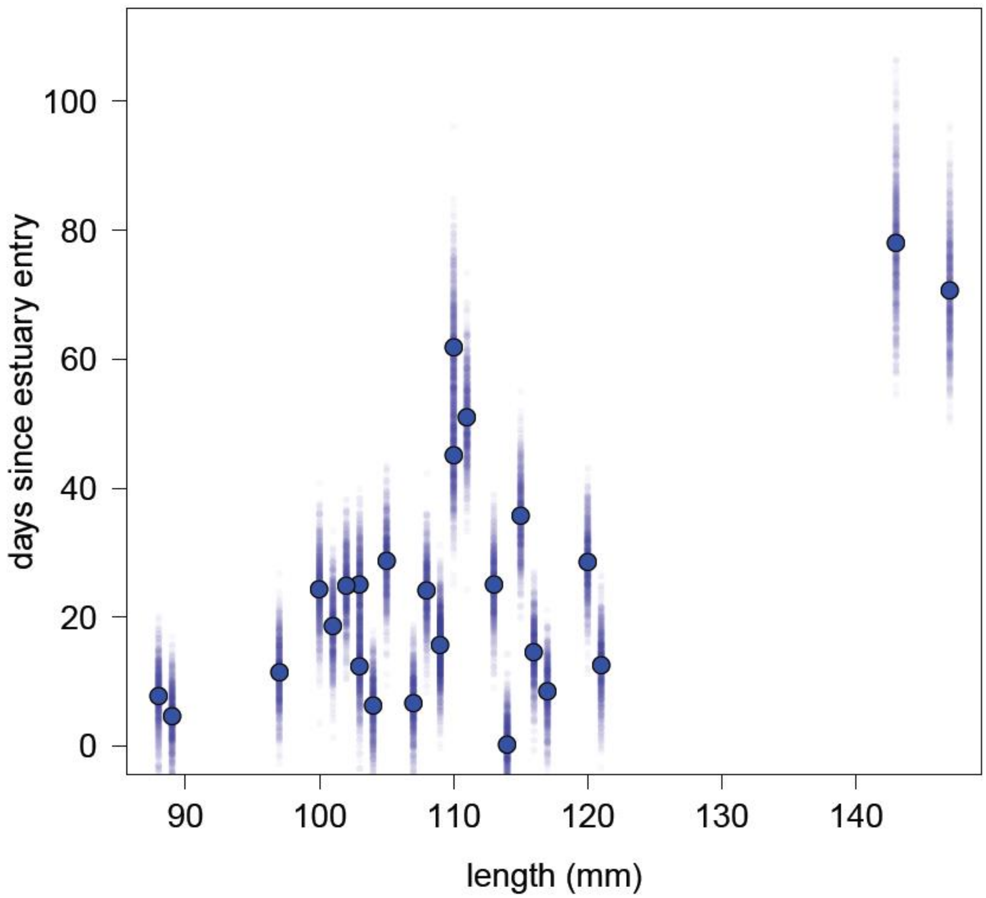


Fig. 13. Estuary residence of Chinook salmon juveniles. Days since estuary entry was estimated using stable isotope clocks, and is shown as a function of size at capture. Density of small points represent bootstrapped estimates to shown the range of possible residence estimates and the larger points are the average estimates. Shown here are estuary entry estimates based on d13C and muscle tissues.

ENERGETICS

We also initiated a preliminary study into the energetics of the juvenile sockeye salmon that were entering the Skeena River estuary. In large river systems like the Skeena River, juvenile salmon have to migrate enormous distances from where they rear downstream to the estuary. In some cases, the energetic costs of migration may push smolts to the point where they are 'running on empty' by the time they get to the estuary. Estuary resources are required to replenish energy stores and for growth during the critical early marine life-history stage. Understanding the energy stores of juvenile salmon as they enter the estuary can provide insight into how sensitive salmon may be to changes in estuary prey resources.

In the 2015 field season we collected 78 sockeye smolts in Inverness Channel and Flora Bank and analysed them in the lab for lipid content. Lipid constitutes the best energy source for fish and measuring the percent lipid (gram lipid per gram body weight) reflects the amount of energy fish have stored. We found that on average sockeye smolts were 2.6% lipid. Ten percent of fish were less than 2% lipid, where 1.5% is thought to be a threshold where salmon performance begins to deteriorate (death). These data indicate that a substantial proportion of juvenile salmon have low energy stores when they reach the estuary (Fig. 14). These data are evidence that some sockeye salmon juveniles are close to starvation when they reach the estuary.

Key finding: Juvenile sockeye salmon have variable energetic stores in the estuary; some individuals had low energy levels indicative of starvation.

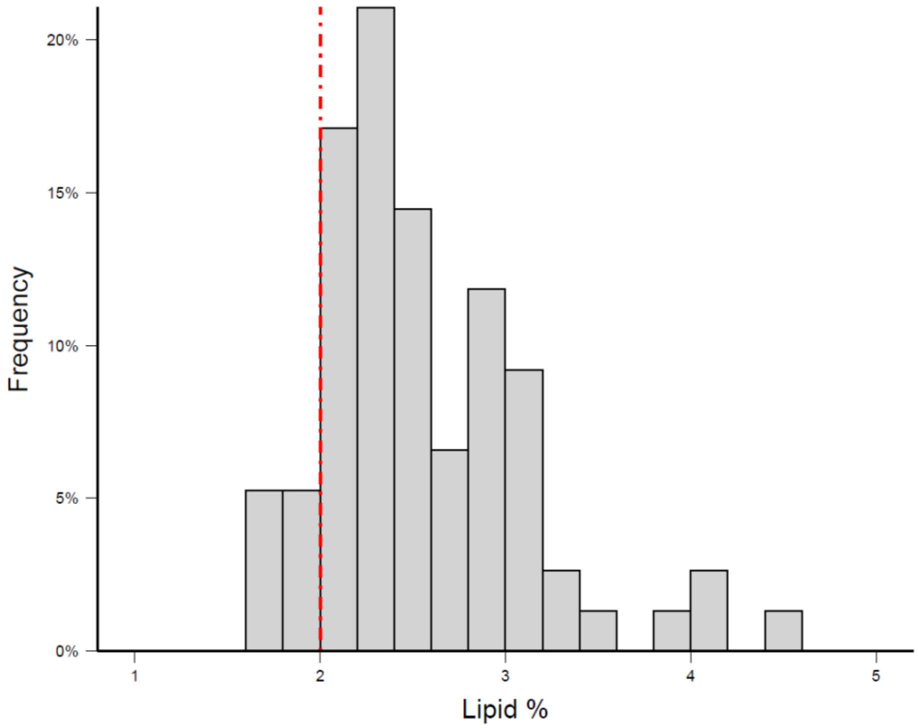


Fig. 14. Frequency of energy storage levels of smolts captured in the Skeena Estuary. Red line at 2% indicates energy ‘danger zone’- where 1.5% is thought to be a threshold where salmon performance begins to deteriorate (death).

GENETICS OF SALMON FROM FLORA BANK

Because salmon return to the same place where they are born, they have evolved remarkable adaptations to their ecosystems. For example, there are likely hundreds of uniquely adapted salmon populations in the Skeena River watershed (Gottesfeld and Rabnett 2008). Working with the Fisheries and Oceans molecular genetics laboratory, we performed genetic analysis of salmon caught in the Flora Bank region of the estuary to examine which salmon populations use this part of the estuary. Genetic analyses were performed on sockeye salmon and Chinook salmon but were not performed on pink, chum, and coho salmon juveniles as their genetic population structure is poorly refined. There are approximately 60 total populations (Chinook and sockeye) that can be reliably separated with microsatellites in the Skeena River watershed (Beacham et al. 2005). Small pieces of the caudal fins were collected for genetic analyses from a subsample of Chinook and sockeye salmon collected in the Flora Bank region of the estuary. DNA was extracted and amplified by polymerase chain reaction at 13 and 14 microsatellite loci for Chinook salmon and sockeye salmon.

The genetic assignment outputs probabilities that a given fish is from the population of interest. As a conservative approach, we only used the most likely probability in our calculations. The probability (*P*) that at least one fish captured in the estuary was from the population of interest was calculated as a function of the product of the *n* individual probabilities that estuary fish came from that population of interest (X_i):

$$P = (1 - \prod_{j=0}^{n}(1 - X_j)).$$

We now have collected three years of genetic stock identification data. Genetic data from the 2013 field season were previously published (Carr-Harris et al. 2015), updated with the 2014 genetics in a more recent publication (Moore et al. 2015). Here we provide the most complete data based on the 2013, 2014, and 2015 field seasons.

Key finding: Flora Bank supports more than 50 genetically-unique salmon populations that come from the traditional territories of at least 11 First Nations.

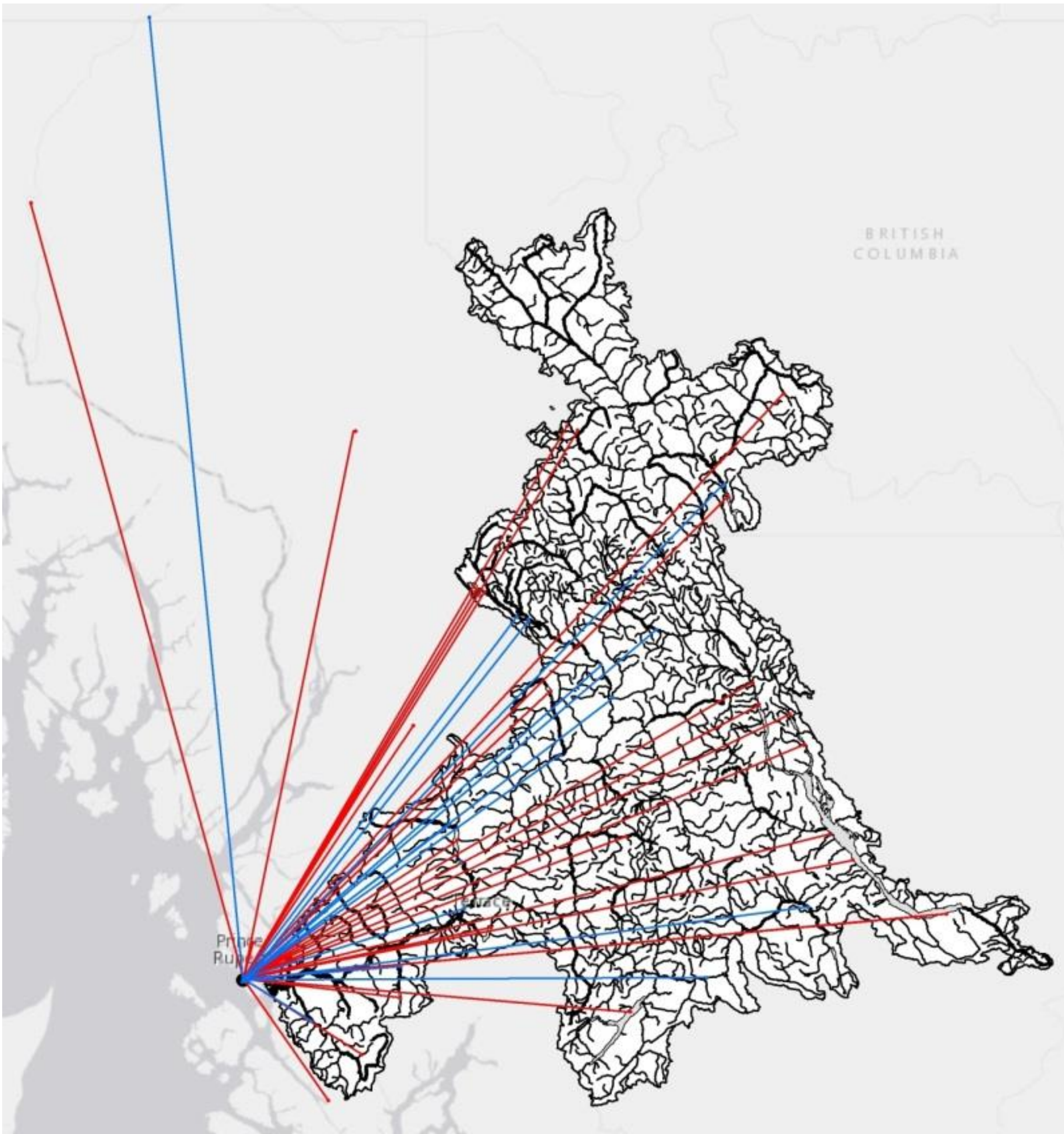


Fig. 15. The Flora Bank region supports salmon from throughout the Skeena River watershed and beyond. Lines connect fish collected in the estuary with where they are from. Red lines represent sockeye salmon, blue lines represent Chinook salmon. Map created by John Latimer of Lax Kw'alaams fisheries, based on results from 2013 and 2014 (Moore et al. 2015).

Across these three years, we have collected genetics from juvenile salmon from dozens of populations. Based on the most up-to-date data, Chinook salmon collected in the Flora Bank region come from 21 different populations, ranging from populations from far inland such as Morice and Bear River populations, to more coastal populations such as from the Ecstall and Kalum Rivers (Table 1). Sockeye salmon collected on Flora Bank had DNA that assigned to 31 different populations. Sockeye salmon included individuals genetically assigned to coastal populations (e.g., Diana Creek of the Kloiya), major Skeena producers (e.g., Fulton and Pinkut populations of the Babine system), lower Skeena populations (e.g., Williams of Lakelse Lake), and inland populations (e.g., Bear and Sustut populations). Some of the sockeye salmon collected were identified as coming from populations of conservation concern, such as the Nanika population from Morice Lake and sockeye salmon from Kitwanga Lake (Table 1). Genetics data also reveal that juvenile sockeye salmon from other watersheds, both to the north and the south, also use the Flora Bank region—some sockeye salmon juveniles were identified as being from the Stikine, Bowser Lake of the Nass, and Marble Creek from the Rivers Inlet area. Thus, more than 50 populations of salmon use the Flora Bank region (Table 1). It should be noted that these are minimum estimates—the more fish we sample, the more populations we discover that use the Flora Bank region.

These data are evidence that the estuary habitats proposed for development supports fish that are harvested in commercial, recreational, and Aboriginal fisheries throughout the Skeena watershed and beyond (Fig. 15). In a letter in the journal *Science* published August 2015 (Moore et al. 2015), we highlighted that these fish come from >10 different First Nations territories yet only five had been consulted by PNW LNG. The updated data now demonstrates that Flora Bank supports fish that originated from the traditional territories of at least 11 different First Nations (Table 1).

Table 1. Genetically-identified Chinook and sockeye salmon from the Flora Bank region of the Skeena River estuary. This table also shows the First Nations whose territories include the salmon population. Updated from (Moore et al. 2015).

Species	Population	First Nation[1]	Probability[2]
Chinook salmon	Babine	Gitxsan and Lake Babine	1
Chinook salmon	Bear	Gitxsan and Takla Lake	1
Chinook salmon	Bulkley early	Wet'suwet'en	1
Chinook salmon	Cedar_early	Kitsumkalum	1
Chinook salmon	Ecstall	Lax Kw'alaams and Kitsumkalum	1
Chinook salmon	Exchamsiks	Lax Kw'alaams and Kitsumkalum	1
Chinook salmon	Fiddler Creek	Kitselas	0.92
Chinook salmon	Gitnadoix	Lax Kw'alaams and Kitsumkalum	0.93
Chinook salmon	Khyex River	Lax Kw'alaams and Kitsumkalum	0.23
Chinook salmon	Kitwanga	Gitxsan and Gitanyow	1
Chinook salmon	Kuldo Creek	Gitxsan	1
Chinook salmon	Lower Kalum	Kitsumkalum	1
Chinook salmon	Morice	Wet'suwet'en	1
Chinook salmon	Nangeese River	Gitxsan	1
Chinook salmon	Shegunia River	Gitxsan	1
Chinook salmon	Slamgeesh	Gitxsan	0.89
Chinook salmon	Squingula River	Gitxsan	1
Chinook salmon	Sustut	Gitxsan and Takla Lake	1
Chinook salmon	Sweetin	Gitxsan	0.8
Chinook salmon	Tatsamenie	Tahltan	1
Chinook salmon	Zymagotitz River	Kitsumkalum	0.85
Sockeye salmon	Kitwanga	Gitanyow	1
Sockeye salmon	Freda Lake (Area 5)	Lax Kw'alaams	0.99
Sockeye salmon	Slamgeesh / Damshilgwet	Gitxsan	1
Sockeye salmon	Swan Lake (Kispiox)	Gitxsan and Gitanyow	0.99
Sockeye salmon	Stephens Lake (Kispiox)	Gitxsan	1
Sockeye salmon	Mcdonell Lake (Zymoetz)	Gitxsan and Wet'suwet'en	1
Sockeye salmon	Nanika (Morice Lake)	Wet'suwet'en	1
Sockeye salmon	Kalum Lake	Kitsumkalum	1
Sockeye salmon	Williams (Lakelse Lake)	Kitselas	1
Sockeye salmon	Shulbuckhand (Lakelse Lake)	Kitselas	0.51
Sockeye salmon	Four Mile (Babine)	Lake Babine Nation	1
Sockeye salmon	Fulton (Babine)	Lake Babine Nation	1
Sockeye salmon	Grizzly (Babine)	Lake Babine Nation	1
Sockeye salmon	Lower Babine (Babine)	Lake Babine Nation	1
Sockeye salmon	Pierre (Babine)	Lake Babine Nation	1

Sockeye salmon	**Pinkut (Babine)**	**Lake Babine Nation**	**1**
Sockeye salmon	**Tahlo (Morrison)**	**Lake Babine Nation**	**1**
Sockeye salmon	**Morrison (Morrison)**	**Lake Babine Nation**	**1**
Sockeye salmon	**Upper Babine (Babine)**	**Lake Babine Nation**	**1**
Sockeye salmon	**Alastair Lake (Gitnadoix)**	**Lax Kw'alaams**	**1**
Sockeye salmon	**Diana Creek (Kloiya)**	**Lax Kw'alaams**	**0.66**
Sockeye salmon	**Johnston Lake (Ecstall)**	**Lax Kw'alaams**	**1**
Sockeye salmon	**Shawatlan Lake (Coastal)**	**Lax Kw'alaams**	**1**
Sockeye salmon	**Prudhomme Creek (Coastal)**	**Lax Kw'alaams**	**1**
Sockeye salmon	**Bowser Lake (Nass)**	**Nisga'a and Gitxsan**	**1**
Sockeye salmon	**Gingit (river type)**	**Nisga'a**	**0.28**
Sockeye salmon	**Stikine**	**Tahltan**	**0.75**
Sockeye salmon	**Bronson Slough (Stikine)**	**Tahltan**	**0.54**
Sockeye salmon	**Bear Lake**	**Takla Lake and Gitxsan**	**1**
Sockeye salmon	**Sustut Lake**	**Takla Lake and Gitxsan**	**1**
Sockeye salmon	**Marble Creek (Oweekeeno)**	**Wuikinuxv**	**1**

[1]Our general approach was to be inclusive given overlapping territories without implications of resolution of disputes.

[2]The probability (*P*) that at least one fish captured in the estuary was from the population of interest, calculated as described in the text.

HISTORICAL CONTEXT

Our research represents the most recent phase of studies by fisheries scientists. There is a history of science in the region and it has repeatedly identified the Flora Bank region as particularly important habitat for salmon and should be avoided for industrial development.

For example, in 1972, a large sampling program was conducted by fisheries scientists on behalf of the Province and found that the Inverness Passage, Flora Bank, and De Horsey Bank had the highest catch-per-unit-efforts of juvenile salmon out of any location (Higgins and Schouwenburg 1973). They also observed migration of juvenile coho salmon until late July and Chinook and chum salmon all the way into August, evidence that these species may be rearing in the estuary for several months. They also found that Flora Bank had the highest abundances of “needlefish” (*Ammodytes hexapterus*), what are now also commonly called Pacific Sand Lance, and are important forage fish for marine mammals and piscivorous fish like Chinook salmon. Our research findings echo these historic studies. The scientific evidence supporting the importance of Flora Bank has not weakened over the last forty years; to the contrary, our analyses strengthen this conclusion.

Previous industrial proponents and decision-makers considered these early scientific studies and avoided developing this area due to risks posed to estuary habitats for salmon and other fish (Fig. 16). An analyses of Port Development suggested avoiding the area as a potential site for a bulk terminal because of the “fish feeding grounds of Flora Bank” (Wright Engineers 1972, Northcoast Environmental Analysis Team 1975). Previous proponents of LNG have decided not to build in the Flora Banks areas and noted the high risks to fish (Tera Environmental Consultants 1981). Specifically, Dome Petroleum hired consultants for an analysis of potential LNG sites; a potential site on Smith Island (immediately SE of Lelu Island) was given the worst ranked score in the Skeena/Nass region in terms of aquatic risk out of all of the sites—that it, this site was ranked worst because of the “greatest impact” to aquatic environment (Tera Environmental Consultants 1981).

Scientists have repeatedly found that the Flora Bank region is particularly important to juvenile salmon and other key fish species. The scientific findings have not changed, except now we have even more understanding of the risks large-scale development poses to fish resources in this location. Experts have repeatedly recommended that industrial development be avoided in this area. Furthermore, industrial proponents have repeatedly avoided this area due to the risks to salmon.

> recommendation that because of these values, no port development take place on the Flora Bank - Kitson Island site.
>
> --Higgins and Schouwenburg 1973, report to Province of B.C. 1973

> A limiting factor to the development of the Kitson Island site for a bulk terminal is the detrimental effect it could have on the fish feeding grounds of Flora Bank.
>
> --Wright Engineering 1972, in report to Port Development, Prince Rupert

> The environmental evaluation indicated that the Kitson Island site would result directly in a large impact on anadromous fish. Related industrial development on Flora Bank would intensify this impact, and would add a major waterfowl impact as well. Accordingly, this option was judged to be environmentally unacceptable.
>
> An assessment of the regional environmental values indicated that the most valuable areas occur around Flora Bank (salmon and waterfowl
>
> --Northcoast Environmental Analysis Team 1975, in reviewing potential sites for a Prince Rupert Bulk Loading Facility.

Fig. 16. Examples of quotes from historic scientists and decision-makers regarding environmental risks of development in the Flora Bank region.

PATHWAYS OF RISK

Previous science has found that salmon populations do poorly in industrialized estuaries. For instance, Chinook salmon survival was three times lower in estuaries with high levels of development (Magnusson and Hilborn 2003). Other comparative studies have found similar patterns where salmon survive more poorly in more industrialized estuaries (Meador 2014). However, it is critical to note that previous studies have not identified one sole pathway by which industrial development negatively impact fish—in fact there are many different pathways of impact that likely contribute to this pattern and they may act together.

Habitat degradation. One major concern is that Flora Bank, and its eelgrass, could be eroded by the PNW LNG project. Dr. McLaren, of the Science Team that worked with Lax Kw'alaams, has discovered that Flora Bank is likely held in place by the balance of tidal and wind energy from the west and the Skeena River flow from the east. The pilings from the bridge/trestle could disrupt this balance, and Flora Bank and its eelgrass could erode.

Eelgrass undoubtedly represents important estuary habitat for juvenile salmon, providing food and refuge (Semmens 2008), but it is likely only one dimension of what makes Flora Bank important to juvenile salmon. It is quite possible that the project could damage fish and fisheries even if the eelgrass is not disrupted, as outlined below.

Bridge/trestle. The proponent has substantially modified their plan so that it now includes a 2.2 km bridge/trestle out to the tanker dock. Previous research by scientists from the University of Washington discovered that young salmon avoid swimming under bridges in estuaries and that the area under bridges represents poor salmon habitat (Toft et al. 2007, Munsch et al. 2014). It is not known why—perhaps the bridges attract predators of salmon—but these findings mean that a vast bridge across the pathway of hundreds of millions of juvenile salmon poses a significant risk pathway. This risk has not been acknowledged by the proponent.

Other. Estuaries are complicated and dynamic ecosystems, sustained by the mix of rivers and ocean. This food web, of which salmon are just one part, could be easily altered by a large project such as PNW LNG. Pathways such as noise, contaminants, shipping traffic, accidental spills, and increased fishing pressure may contribute to degradation of this ecosystem. Further, marine sediments around Lelu and Ridley Island, and Porpoise Channel are known to be contaminated with organic compounds (dioxins and furans) released from the now derelict Skeena Cellulose pulp mill on Watson Island. The impacts to the estuary food web from resuspending these compounds are poorly understood. Resuspension may result from dredging activities associated with constructing the MOF for PNW LNG in Porpoise Channel, dredging sediments for the pipeline to reach the terminal, or the Canpotex bulk potash facility on Ridley Island, and other proposed facilities. Incidental spills of fuel is also a substantial risk pathway (e.g., bunker fuel), as relatively low levels of oil can prevent the hearts of young fish from developing properly (Incardona et al. 2014).

This report focuses on juvenile salmon, but salmon are just one group of marine species that could be impacted by the PNW LNG proposal. We have caught thousands and thousands of individuals of many other fish species, such as Pacific herring, which also support fisheries and the greater ocean food web. There are also major knowledge gaps of what makes key habitats for these other species, these knowledge gaps have not been addressed by the proponent.

THE UNCERTAIN SCIENCE OF MITIGATION

The proponent has outlined a mitigation strategy that they claim will compensate for habitat destruction associated with the proposed development. The body of scientific research does not support this claim—in fact, it appears that mitigation is only occasionally successful. Here we briefly review the scientific data regarding the efficacy of different aspects of habitat mitigation.

One principle behind much of the current approach to mitigation is the idea of 'no net loss'. Habitat that is lost due to development should be replaced with equal or greater habitat, in an effort to sustain the support of ecosystem services such fisheries. Despite this conservation goal, a field audit conducted in 2000-2001 (Harper and Quigley 2005, Quigley and Harper 2006) reported that of the projects approved between 1994 -1997, over half would probably violate the Fisheries Act. On average projects were 343% larger than authorized and 67% of projects ultimately resulted in a net loss of fish habitat. Despite statements of commitment from developers, stated habitat compensation targets were not being met more often than not.

Reviews of the literature indicate that when restoration happens, it only sometimes leads to the desired biological response. These are examples of restoration successfully increasing fish or insect diversity, numbers, or productivity, but large reviews of the literature indicate that these successes may be the minority rather than the majority. Watershed-scale processes are still understudied, operate on large spatial and temporal scales, and are thus difficult to replicate (Beechie et al. 2010). One stated goal of restoration is to increase functional redundancy and biodiversity. Yet, a review of 78 restored streams with this goal found that only two streams had increased biodiversity as a result of restoration (Palmer et al. 2010). Additionally, an overarching review of studies on biodiversity and ecosystem services found that restored ecosystems had higher biodiversity than degraded ecosystems, but decreased biodiversity compared to reference systems (Benayas et al. 2009). These findings suggest that while restoration is a valuable strategy for already degraded systems, restored systems generally do not provide the biodiversity and natural resources of intact systems. The vast majority of restoration is not effectively monitored, making it difficult to assess efficacy (Bernhardt et al. 2005).

In order to effectively mitigate habitat degradation, there needs to be an established link between a species and the habitat it relies upon. This is not the case for juvenile salmon in estuaries, let alone the other species of importance in the area (e.g., smelt, herring, etc.). While eelgrass is obviously important for some salmon species (especially Chinook salmon, e.g., (Semmens 2008)), other species may rely more on other aquatic vegetation, others may need rocky reefs, while others may need specific zooplankton prey and the right levels of turbidity and salinity. Thus, mitigation strategies may target the wrong specific habitat type.

Eelgrass planting in particular has a varied history of success. In some cases it appears to work, while in other cases, most, if not all, transplanted eelgrass die (Zimmerman et al. 1995, Li et al. 2010). The success of eelgrass transplants can depend on site characteristics--eelgrass can be sensitive to sediment deposition, light attenuation, and other factors (Zimmerman et al. 1995, Park and Lee 2007).

Our research discovered that eelgrass habitats are not used equally by salmon—Flora Bank eelgrass had 20X more juvenile salmon than other eelgrass—which calls into the question the assumption that creation of new eelgrass will compensate for destroyed Flora Bank eelgrass.

Based on this body of research, it is our scientific conclusion that habitat mitigation will be unlikely to succeed.

CONCLUSIONS

Our data, as well as the past body of science and analyses of the proponent EA, have led us to the following scientific conclusions:

1. ***The PNW LNG project is proposed for a location that is especially important for salmon from throughout the Skeena River.***

2. ***Because of its poor site choice, the PNW LNG project poses significant and unacceptable risks to Skeena salmon and their fisheries.***

3. ***The proponent has systematically failed to adequately assess the risks to fish and fisheries.***

4. ***Project approval would disregard science, fish population health, and Aboriginal Rights.***

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