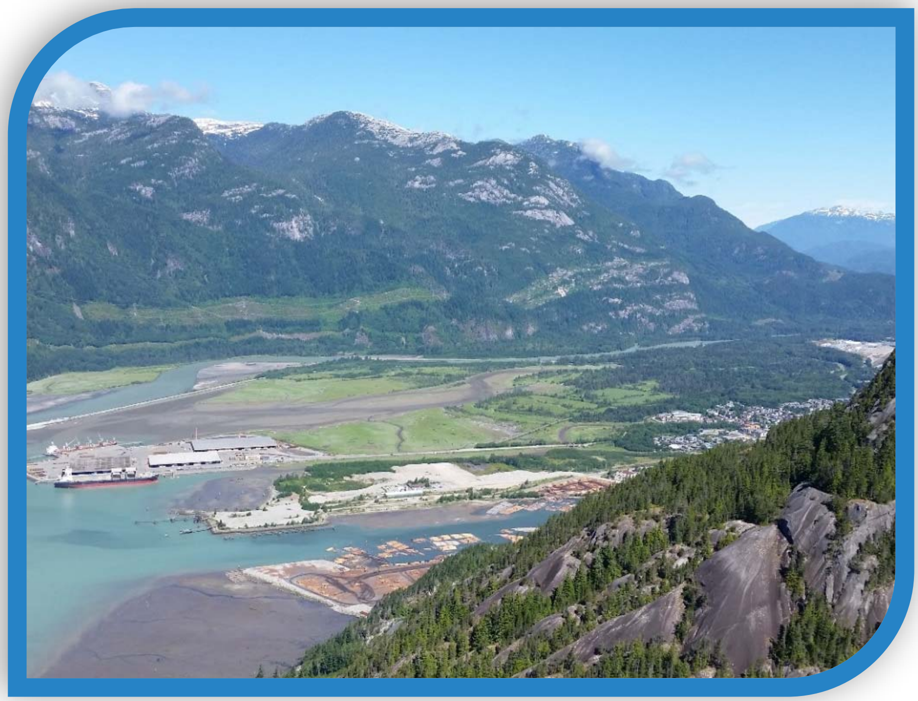
Squamish River Estuary Overview Report



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Tidal waters of fjordal Atl'kitsem ebb and flow as glacial
Squamish empties itself into the vast estuary: slowing,
settling always changing: mudflats form its heart and soul.

E. Tobe

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EXECUTIVE SUMMARY

The Squamish Estuary has undergone numerous changes over the past 70 years. Some of these changes include infilling, confinement of the river through a "Training Dike" designed to move the river to the west side of the estuary, urban expansion, and forestry activities including construction of the Woodfibre pulp mill and former Interfor sawmill. The result of these changes has been dramatic losses to fish and wildlife and estuary functions.

In order to mitigate and offset some of these impacts, efforts have been made by various organizations over the years to undertake habitat restoration (defined in side bar to right) in order to improve access to the estuary for fish and wildlife and estuarine function. Some of these efforts have resulted in the reconnection of tidal channels, installation of culverts across roads and dike, and conversion of brownfields and industrial lands back into natural estuary.

In recent years, the Squamish River Watershed Society, in partnership with Squamish Nation and Fisheries and Oceans Canada, has been studying these restoration efforts to determine their effectiveness. The tidal channel restoration has resulted in substantial benefits to plants and wildlife that require the brackish waters of the estuary, particularly, increases in habitat for spawning, rearing, and overwintering salmonids. As well, in 2005 an arch culvert was placed along the West Barr Log Sort Road to improve tidal exchange across the lower end of Pretty Slough (through Site A). This was followed in 2016 with the partial deactivation of the Logging Road south to the brownfield restoration site (renamed West Wind Restoration), resulting in the restoration of over 4.7 hectares of habitat. However, recent studies identified limited access across the Training Dike, whether it was the placement or sizing of the culverts which appear to restrict access to the Central Estuary from out-migrating juvenile salmonids as they move down the Squamish River and its tributaries.

The Squamish River Estuary Overview Report is intended to provide background information on some of the history of the estuary restoration efforts, including previous studies and reports over the past five decades.

Habitat Restoration:

Habitat restoration is a recent concept in human history. It began in the early 1900s with the recognition that protective measures must be given to wildlife to ensure its survival. Habitat restoration seeks to repair areas that have been subjected to habitat destruction. Habitat destruction is one of the primary factors involved in causing species of plants and animals to be threatened with extinction. Habitat restoration seeks to undue the disturbances to allow the lands to be viable for the future.

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ABBREVIATIONS

BCR – BC Rail
BCRP – BC Rail Properties
Cms – Cubic metres per second
CWT – Coded wire tag
DFO – Department of Fisheries and Oceans Canada
Ha – Hectare
MFLNRORD – Ministry of Forests, Lands, Natural Resource Operations, and Rural Development
DOS – District of Squamish
IBA – Important Birding Area
MOE – Ministry of Environment
PGE – Pacific Great Eastern Railway
RST – Rotary Screw Trap
SECC – Squamish Estuary Coordinating Committee
SEMC – Squamish Estuary Management Committee
SEMP – Squamish Estuary Management Plan
SERC – Squamish Estuary Review Committee
SRWS – Squamish River Watershed Society
ST – Squamish Terminals
TNT – The Nature Trust of BC
WMA – Wildlife Management Area
WUP – Cheakamus Water Use Plan
YoY – Young of year

Skwelwil'em is the original name of the Squamish Nation Island located in what is now downtown Squamish. The first anglicization of the Squamish Nation name "Skwulwailum" occurred in 1867 when the first European settlers came to Squamish. These settlers found platforms built by the local First Nations community high in the spruce trees on the delta which were used as lookouts to watch for raiding parties who came up to Howe Sound periodically on their forays (Anon., 1958). Today, Skwelwil'em remains an active name and has been integrated into the 2007 Wildlife Management Area in the Squamish estuary.

ACKNOWLEDGMENTS

A project of this scale and scope involves the input from numerous experts with varying fields of experience. We would like to thank Fisheries and Oceans Canada, including Dave Nanson, Al Jonsson, Murray Manson, Michael Crowe, as well as retired DFO Matt Foy and Colin Levings who were the pioneers that helped to create the initial vision of restoring the estuary.

Thank you to Squamish Nation Chief and Council, Ta'haxwtn Randall Lewis and retired Chief Gibby Jacob.

Thanks go out to the provincial support team including Brent Gurd, Eric Balke, Scott Barrett, and recently retired Sylvia Letay who have been supportive of the restoration activities within the Skwelwil'em Wildlife Management Area.

Support from the Squamish Terminals and the District of Squamish has been crucial to the development of this study and the long-term restoration proposal.

Local expert and citizen scientist John Buchanan shared much of his knowledge and insight. A portion of the section on Hydrology was co-authored by Erin Pettit. We would like to also thank the Squamish Windsports Society, Squamish Environment Society, Squamish Streamkeepers, My Sea to Sky, and the Howe Sound Biosphere Region Initiative.

Funding support for this study was provided by grants from Habitat Conservation Trust Fund, BC Hydro Fish and Wildlife Compensation Program, Coastal Restoration Fund, and Pacific Salmon Foundation.

Volunteers assisting with planting new restoration site at former log sort Oct 2016 (photo E. Tobe)[1]

[1] Photos included in this document were either contributed (photo credit provided where possible) or taken from internet stock imagery.

INTRODUCTION

The "Squamish River Estuary Overview Report" (henceforward referred to as the "Report") is intended to provide an overview of existing information on the Squamish Estuary that will assist in decision making on upgrades or modifications along the Squamish Training Dike and within the Central Estuary for the benefit of fish and wildlife. The main focus of restoration efforts has been on improvements for salmonids, including their needs for various types of habitat depending upon their life stage, and access between the Squamish River and Central Estuary. The scope of restoration efforts has been expanded to address potential alterations to the lower section of the dike along the Spit that could allow for reconfiguration and the opening of the southern estuary. Furthermore, the Report will also explore the potential installation of an intake structure across the CN Spur Line to reconnect the tidal waters of the Central Estuary with the upper Bridge Pond / Cattermole Slough (Figure 1).

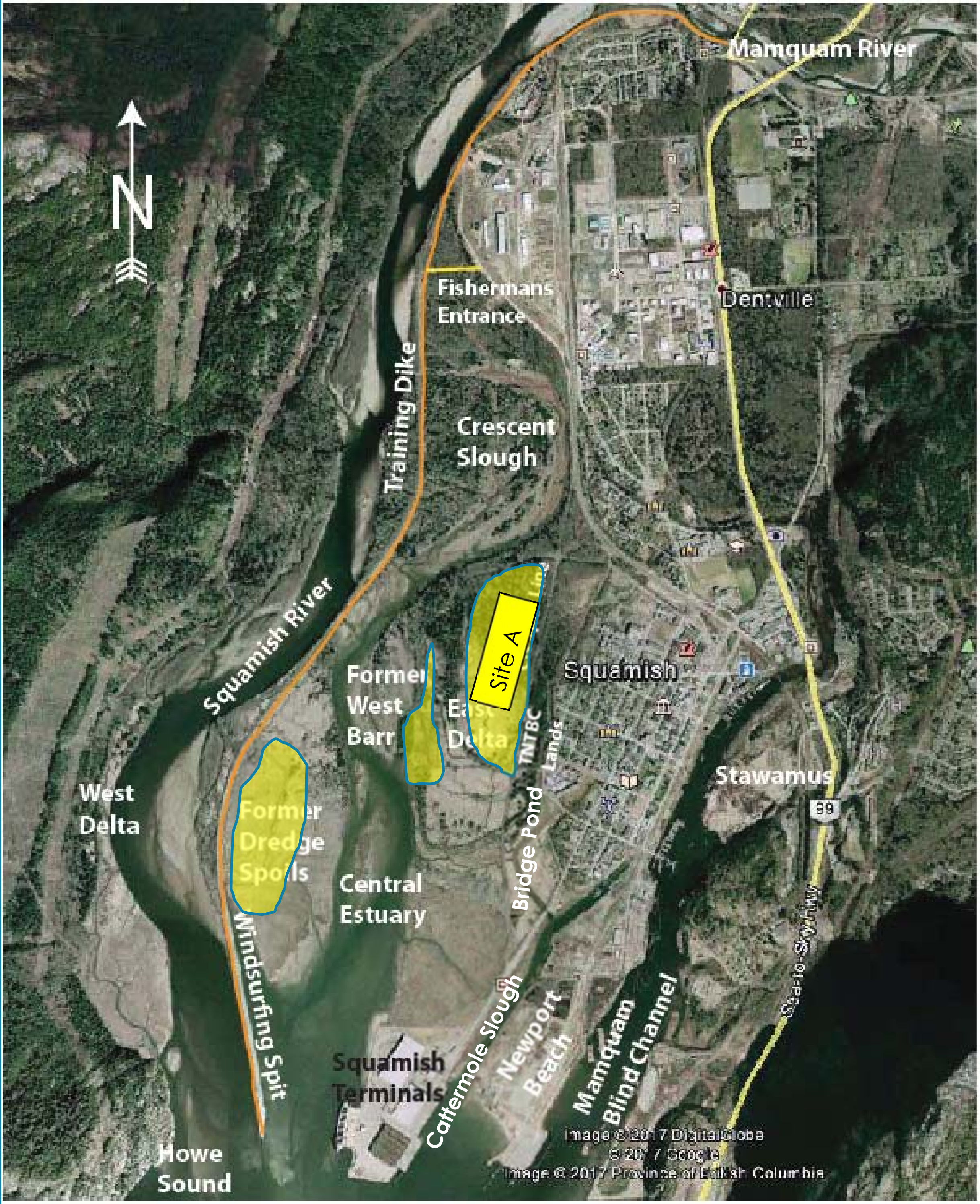


Figure 1. Training Dike & Estuary Site Description

SECTION 1: PROJECT BACKGROUND

RATIONALE BEHIND PROJECT SCOPE

The scope of this Report is to identify restoration opportunities within the Skwelwil`em Squamish Estuary Wildlife Area including improvements to salmonid and other fish access across the Training Dike through culvert access, realignment of the Spit, and installation of an intake structures across the CN Spur line to reconnect the tidal waters of the upper Cattermole Slough with the Central Estuary (Figure 1). Additional goals include a literature review of previous studies and research on the estuary.

From the 1950s onwards, the vision for the town of Squamish was to develop the waterfront as a major industrial hub. To this end infilling, log booms, road and dike construction was undertaken. It was only in the mid-1990s that efforts to restore the impacts from this expansion were initiated. In 1994 restoration included the installation of a culvert crossings along the Training Dike which was followed a decade later with other restoration efforts.

The benefit of these restoration efforts has been significant and is reflected in the monitoring and wildlife counts conducted by various groups and governments. The Squamish Environment Society has been studying bird usage in the estuary since the early 1980s through monthly bird counts[2].

Fisheries and Oceans Canada has been studying salmonid usage associated with the restoration works since 1997 (DFO, pers. comm). The Squamish River Watershed Society has commissioned several studies on the success of vascular plant recolonizing in restored areas (Page, 2004), how flora and fauna have benefited from restoration efforts (Gebauer, 2007), and how juvenile salmonids, particularly Chinook salmon, are utilizing the estuary (InStream, 2018). Table 1 in Appendix 1 summarized some of the major restoration accomplishments to date.

1970 – 1999 SQUAMISH ESTUARY MANAGEMENT PLANNING

In the late 1970s the Provincial and Federal Governments determined an estuary management plan would be beneficial to strike a balance between industrial, commercial, recreational, and conservation within the estuary. To this end numerous studies were commissioned on fish usage, vegetation colonization, benthic communities, wildlife usage, sediment flux, recreation usage, and water quality within the Squamish Estuary. In 1982 the first draft of the Squamish Estuary Management Plan designated 394 ha for conservation, 271 ha for industrial development, and 258 ha for further assessment (SEMP, 1999).

[2] Squamish Environment Society birding: http://www.squamishenvironment.ca/programs/squamish-birders/

The 1982 SEMP document was the guiding document for over 15 years but was updated in the 1990s with input from First Nations, the community, and stakeholders. The result of this process was the creation of a multi-jurisdictional plan that was signed off by Environment Canada, Department of Fisheries and Oceans Canada, BC Rail Properties, District of Squamish, and Ministry of Environment and Lands in 1999 (SEMP, 1999). The new revised estuary management plan resulted in 579 ha of the estuary designated for conservation, 350 ha for development, and 8 ha for further planning assessment along the upper Mamquam Blind Channel (Figure 2). Within the conservation lands, 30 ha of environmentally sensitive lands were designated for transfer to Squamish Nation as part of an area known as Site "A" which was completed in 2007 (Figure 1).

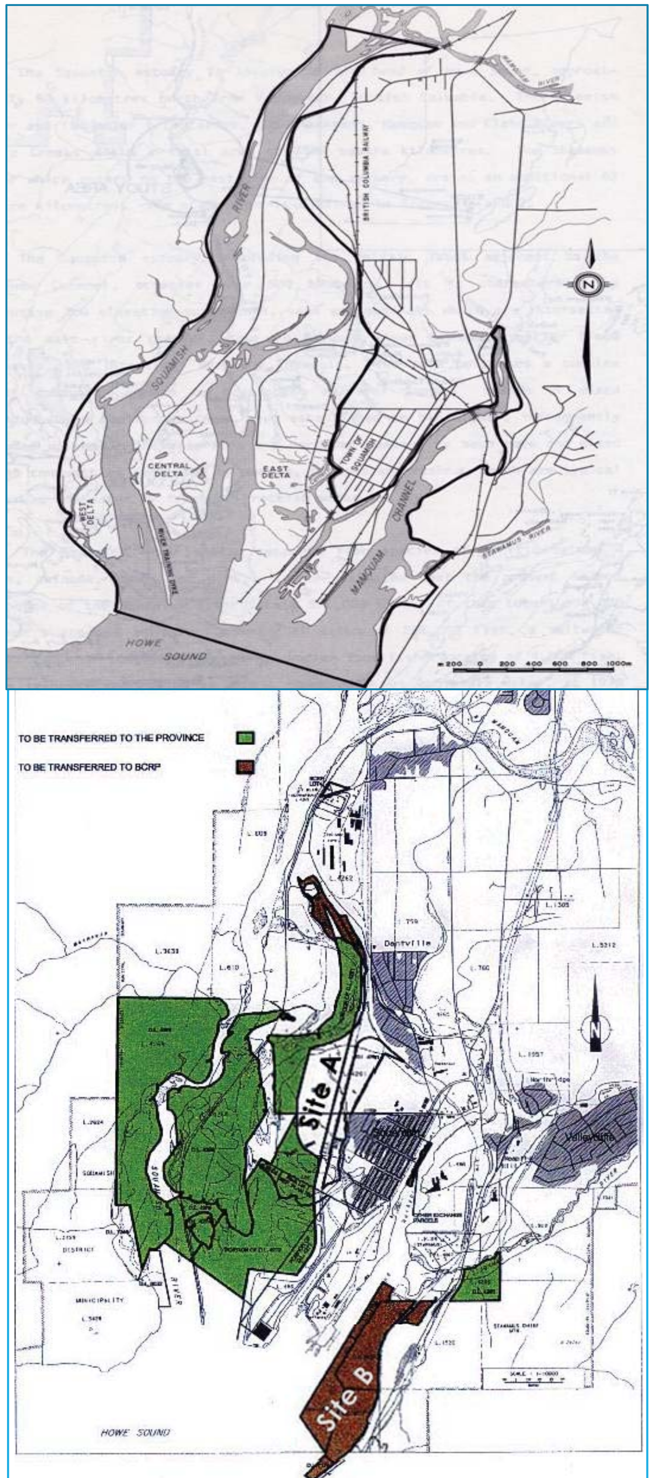


Figure 2. Boundary of Squamish Estuary Management Plan and land transfer

During the period of time from 1970 to the early 1990s the Federal and Provincial governments of the day commissioned scientific, planning, and research studies to better understand the estuary. However, from the early 2000s onwards, restoration activities, scientific studies, monitoring, and research have fallen upon the educational institutes, First Nations, and the non-profit sector.

Some of the recommendations from earlier studies and the 1982 and 1999 SEMPs were to improve fish habitat and implement restoration and enhancement activities. Of particular interest were the following:

- construction of culverts through the Training Dike;
- improvements to fish access across the Training Dike culverts through construction of trash racks to control the movement of debris;

- construction of new habitat or rewatering historical tidal channels cut off by the construction of the Training Dike;
- removal of the dredge spoils pile at the south end of the Training Dike; and
- decommissioning of the West Barr log sort operation (SEMP, 1999).

1999 – 2018 RESTORATION ACTIVITIES

From 2001 to the present the Squamish River Watershed Society (SRWS) has worked with DFO and other partners (MFLNRORD, Squamish Nation, DOS) to achieve many of the goals of the 1999 SEMP with the successful completion of the following restoration works. Appendix 1 (Figure 7) contains a detailed summary of the restoration works:

- installation of an additional 4 culvert crossings (for a total of 9 crossings) along the Training Dike;
- installation of trash racks on the river side of the culvert inlets along the Training Dike;
- removal of dredge spoils (originally intended as pre-load material for future port development) near the south end of the Training Dike and re-creation of tidal channels resulting in the restoration of over 15 ha of functional estuarine habitat and creation of a new nature trail (Seagrass / Chelem Trail);
- installation of two culverts along the West Barr Logging Road, including trash racks, and restoration of the Pretty Slough (former Cattermole Slough extension);
- construction of over 10,000 m^2 of tidal channel habitat creation along the east delta including new tidal channel construction in Site "A";
- construction of over 12 pedestrian bridge structures to cross new tidal channels along former agricultural dikes;
- decommissioning of the West Barr brownfield log sort site through removal of upland fill materials, regrading and recontouring of the log sorting basin, re-creation of tidal channels and removal of extensive deposits of wood waste (hog fuel) fill resulting in 4.3 ha of restored fully functional estuarine habitats:
- conversion and reclamation of over 750 linear metres of the West Barr Logging Road into tidal channel and estuarine habitat;
- construction of over 15,000 m^2 of restored habitat along the Central estuary through reconnection of tidal channels along the east side of the Training Dike and provision of access for nature study (including the Woodpecker Trail);
- monitoring reports and scientific studies and research;
- planting of over 3,000 eelgrass shoots (*Zostera marina*), 10,000 sedge plugs (*Carex lyngbyei*), and over 2,000 native trees and shrubs; and
- countless hours of in-kind and volunteer support including assistance with planting, monitoring, scientific studies, and educational programming.

The value of these restoration activities, through direct funding as well as in-kind support of numerous partners, is well over $10 million.

SCIENTIFIC MONITORING & OTHER STUDIES

Monitoring and scientific studies have been an important component of the restoration efforts to determine their effectiveness and to provide a mechanism for adaptive management for the improvement of salmonid and other wildlife habitat. Lessons learned from those studies have guided subsequent physical works and have been an important part of the long-term success to ongoing restoration efforts.

The partnerships between non-profits such as the SRWS, First Nations, and government staff (provincial and federal) has allowed for an adaptive management approach to ensure on-going and as needed improvements to the estuary. To this end a scientific study was commissioned in 2015 to study the usage patterns of juvenile salmonids, particularly Chinook salmon, in the estuary and to determine the extent to which they were utilizing the restoration sites and tidal channels to the east of the Squamish River Training Dike. The result of this study indicated there was lower than expected usage by juvenile Chinook salmon in these locations. This may be precipitated by less than optimum access across the Training Dike via the by culverts (InStream, 2018). Water levels through the culverts are not always adequate to ensure passage of juvenile salmonids (due to fluctuating tidal cycles that range over 4.5 m diurnally).

These findings resulted in meetings and discussions between DFO and SRWS and the project partners to examine options to increase juvenile Chinook salmon (as well as other salmonids) movement across the Training Dike to improve access to the Central and East Estuary areas. Some of the initial recommendations included:

1) exploring the replacement of culverts at key locations with bridges that would allow improved fish passage through the diurnal tidal cycles,

2) realigning the Spit Road to open the southern portion of the estuary, and

3) installation of an intake structure across the CN Rail Spur Line to re-establish flows into the top end of the Bridge Pond.

2017 PROPOSED RESTORATION ACTIVITIES TO TRAINING DIKE & CENTRAL ESTUARY

In the spring of 2017 several meetings were held between the SRWS, Squamish Nation, DFO, Squamish Terminals, District of Squamish, Provincial Ministry (FLNROD), Squamish Windsports Society, Squamish Streamkeepers, and Squamish Environment Society to discuss the proposed restoration plans. The result of these meetings was strong support to allow upgrades along the Training Dike for fish passage provided the following provisions were made:

- minimize impacts from increased sedimentation (which could impact the west berth of the Squamish Terminals);
- provide modelling of hydraulic flow with any culvert replacement or upgrades (to demonstrate no increased flood risk);
- consider impacts to vegetation colonization;

- maintain water access for recreation; and
- continue with stakeholder consultation.

The latter recommendation resulted in a community-based meeting on January 26, 2018 that included discussions around the potential impacts of any changes to the estuary.

In addition to the discussion around modifying culvert crossings at key locations, there was also dialogue around the potential realignment of the southern end of the Training Dike, often referred to as the Windsurfers Spit (henceforward referred to as “the Spit”). As well, there were discussions around the potential to install an intake structure across the CN Spur Line to re-water the to end of the Bridge Pond by reconnecting the tidal slough to the west with Cattermole / Pretty Slough in Site “A”. As a result of these discussions, the SRWS submitted several proposals for funding and was successful in securing funding for physical works within the estuary including:

- upgrading the culvert crossings to improve fish access between the river and the central estuary;
  examining the potential to realign the Spit and restore the original flow of the Squamish River to pre-1972 dike construction conditions; and
  examining the potential to install an intake structure across the CN Spur line to reconnect the tidal channels of the upper Bridge Pond / Cattermole Slough.

Aerial view of Spur Line bisecting Cattermole / upper Bridge Pond (photo Coastal Photo Studio)

SECTION 2: ESTUARY HISTORY

LOCATION

The Squamish Estuary, located approximately 52 km north of Vancouver, is situated at the head of Howe Sound at the confluence of the Squamish River which discharges a drainage area of over 3,650 square km. The Squamish estuary encompasses the tidal waters of upper Howe Sound, from the confluence of the Squamish River upstream to the Mamquam River, the Mamquam Blind Channel, and Stawamus River (refer to Figure 3).

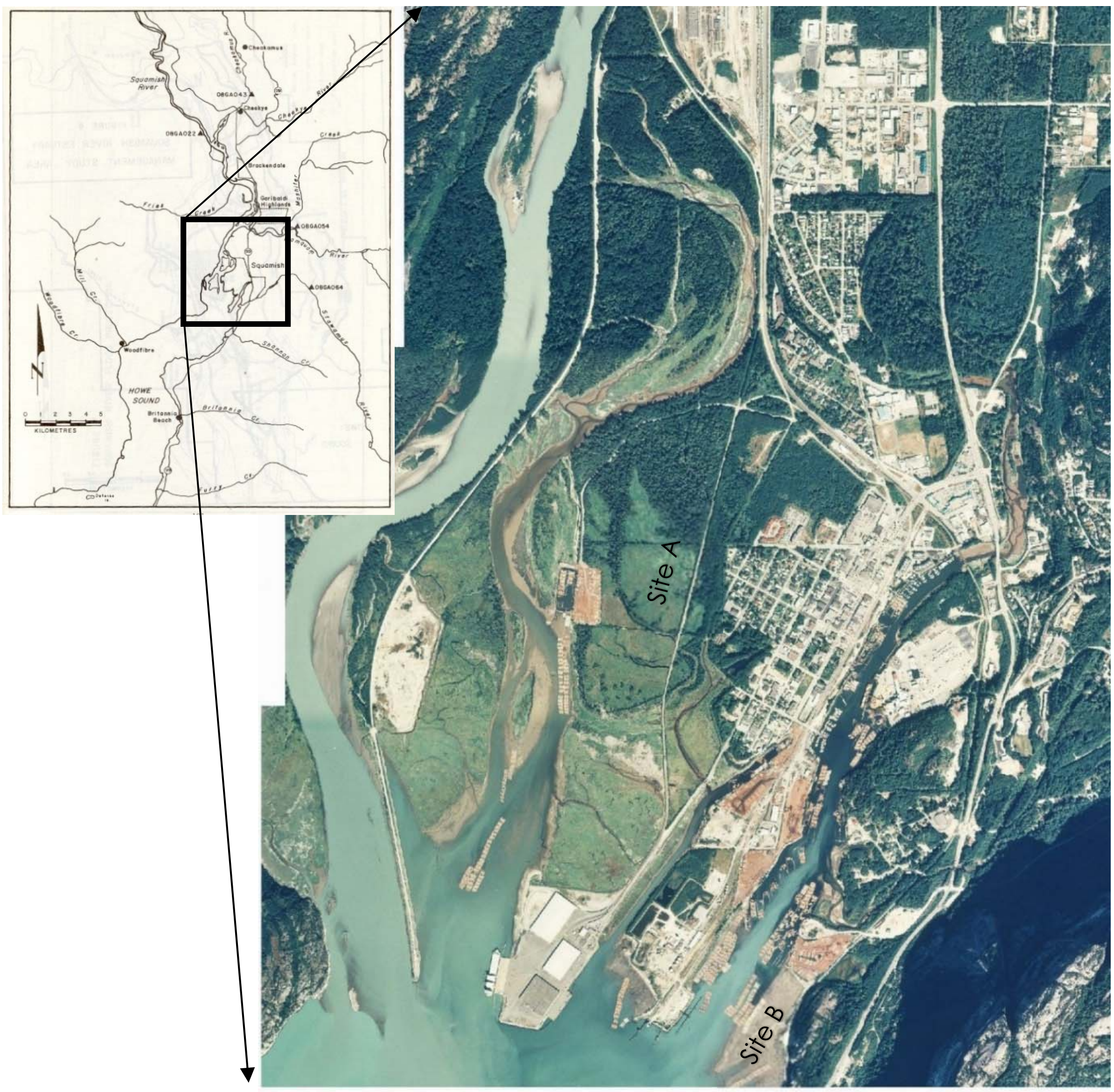


Figure 3. Site map of Squamish Estuary boundaries

HISTORY OF THE SQUAMISH NATION IN THE SQUAMISH ESTUARY

The Squamish Estuary, located in the Salish Sea, is part of a fjordal system, a long, narrow inlet with steep sides and cliffs created over the course of 10,000 years of glacial erosion. This area has been home to Squamish Nation members for thousands of years and has provided food, shelter, and a haven in which their community could expand and thrive. Prior to contact with Europeans, Squamish Nation had various settlements throughout the Squamish Estuary including the villages of Skwawmish Island (IR 21), Ahstan (IR 23), Skwulwailum Island (IR 22), Yekwaupsum, and Sta'amus (which is now present-day Stawamus IR 24) as well as Mamquam Island (IR 20), Defence Islands and Kwum kwum at the head of Howe Sound (refer to Figure 4).

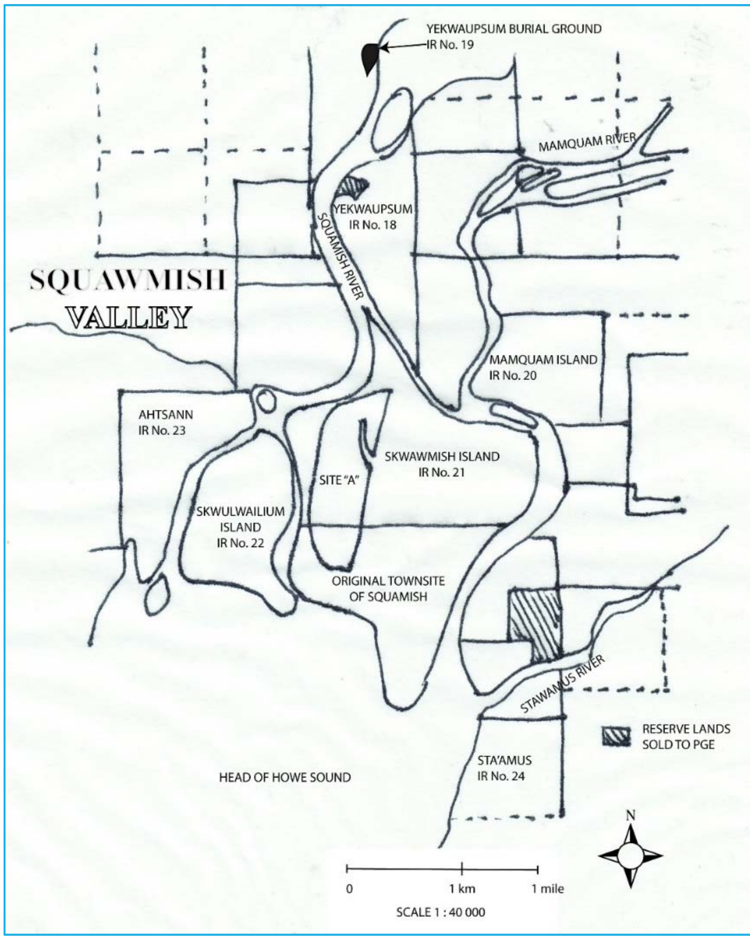


Figure 4. 1876 rendition of the original map of Squamish Nation villages (Bouchard, 1986)

In recent years, historians such as Randy Bouchard and Dorothy Kennedy were able to compile a considerable number of historical documents relating to Squamish traditional territory in its entirety (Bouchard, 2007). Below is a short excerpt from a publication by Bouchard and Kennedy on the Aboriginal History of the Squamish Estuary.

Aboriginal History of Squamish Estuary by Bouchard & Kennedy, 2007:

Most of Site “A” (Figure 1) is located within the traditional territory of the 386-acre Skwawmish Island IR 21 (Figure 4) that was set aside for the Squamish people in 1876 but was subsequently alienated by the PGE Railway Company in 1914-15.

Squamish Nation claims aboriginal title and rights to Skxwumish7ul (Squamish Territory – literally of/belonging to the Squamish). Squamish is an anglicization of the Native term Skwiomish (Squamish people). At the time of British sovereignty in 1846, Squamish people occupied many villages along the Squamish and lower Cheakamus Rivers, as well as a few sites in Howe Sound and Burrard Inlet. Each village contained one or more cedar plank houses constructed along the shorelines or riverbank at a site that offered defence from their enemies, fresh water, and an easy transportation route. One of the most culturally significant sites in Squamish territory was the mouth of the Squamish River. This area was the location of Squamish settlements, both winter villages and seasonal camps; it was a place for harvesting several species of fish and other resources.

While the Squamish diet was varied, by far the single most important elements were the five species of anadromous salmon. An ethnographer comment from 1890 stated that salmon to the Squamish was “what bread is to the European and rice to the Oriental, and great was the distress and famine if the salmon catch was poor” (Hill-Tout 1900: 490-491).

Each species of salmon differed in desirability and availability. Spring Chinook and coho could be taken while still in salt water, but most were caught once they entered the spawning streams. Sockeye, while rare in Howe Sound, were harvested at the Fraser River in the summer. The October running chum were harvested in the rivers where they spawned, and the fish were smoked and dried for storage because of their low-fat content.

Seasonal plants were also harvested in the estuary including thimbleberry shoots and cow parsnip in the spring and rhizomes of bracken fern in late fall or winter. Edible blue camas bulbs were harvested in May and June, after the plant had flowered. the bulbs were pit-cooked for immediate consumption or dried for the winter. Berries of many species were also harvested. Rice root lily played an important role in the diet.

With the influx of European settlers in the late 1800s the estuary was infilled to create the townsite of Squamish along with the industrialization of the waterfront. The estuary underwent vast changes with over 50% of the estuarine lands being developed or infilled.

Squamish Estuary Management Plan Recreation Working Group 1982:

With the completion of the rail link between Squamish and Vancouver in 1956, and a highway in 1958, access to Squamish no longer presented a problem to development. In 1967, Pacific Great Eastern Railway (PGE) announced a "Port Construction Plan".

Shortly thereafter (in 1970), Swan Wooster Engineering was commissioned by PGE to do an in-depth study of land use possibilities for the delta. The analysis concluded that the delta was suitable for development as a manufacturing and trans-shipment point for PGE hinterland natural resources-based commodities. Activities anticipated for the port included the manufacturing, packaging, and exporting of forest products, and the export of coal to Japan. Such an expansion would, it was predicted, swell the population of Squamish to 30,000 and necessitate the relocation of the residential area to north of the delta.

The initial stages of construction were carried out in the early 1970s, but the entire project was never completed. In 1971, approval was granted to commence design work for training of the Squamish River with the construction of a dike. February to April of that year saw the completion of the topographic and sounding surveys of the intertidal of the west and central Squamish Channels, and the beginning of construction of a three-mile long training dike on the east bank of the west channel. In 1972, dredging commenced in this channel and a 106.7 m wide trench was dredged to an elevation of 1.5 m, for a distance of 1646 metres north of the river mouth. In June 1972, construction of the training dike was completed.

It was about this time that public concern over the effects of development on the environment of the Squamish estuary prompted the Department of Environment to undertake an analysis of the entire project.

In 1972 a report by Lands Directorate focused on the human environment of Squamish and the impact and implications of further development of the delta. In terms of physical characteristics, much of the lowland terrain at the southern end of the Squamish valley was observed to be either floodplain or part of an extensive alluvial fan; and the behaviour of the water courses associated with these land forms was considered unpredictable. Terrain on an alluvial fan, such as that of the Mamquam River, was subject to unpredictable hazards owing to channel shifting. Much of the remaining delta (notably the areas designated for future development) were located on an active floodplain.

Basin and landform surveys indicated that the Squamish River floodplain was of poor suitability for urban development (Lands Directorate) and noted that the impacts of the project, and the future back-up development on Indigenous rights, values, and lands, had not been analysed or even considered in any of the planning reports.

Due to the results of the environmental impact studies, and with pressure from interest groups, the port development proposal met with opposition and did not proceed. The history of the port controversy reflects the evolution of public attitudes and of a changing land use emphasis for the Squamish area.

On May 2, 1979, the Canada Department of Fisheries and Oceans and the British Columbia Ministry of Environment jointly announced that a Management Plan would be developed for the Squamish Estuary.

FLOOD DIKING OVER THE PAST 100 YEARS

The townsite of Squamish continued to expand through the early part of the 1900s as it continues its growth well into the 21st Century. In the early 1900s the first flood dikes were constructed around the townsite to address the two main types of flooding: the more common fall flash flood events and the less frequent but more catastrophic spring freshet events (Diehl, 1983). In 1949, it became apparent to the District of Squamish that additional flood protection was required to accommodate the rapidly expanding community. At the request of a local citizen group, the provincial government conducted a series of feasibility studies which culminated in 1965 with a report by B. E. Marr, who at the time worked for the Water Management Branch of the Ministry of Environment. This report concluded that it was economically feasible to provide dike protection for the entire lower Squamish Valley (Diehl, 1983).

Work on flood dikes commenced within a few years. However, while the existing dikes of the day were somewhat successful in preventing flood damages the reliance on dikes as the primary protection against floods contributed to increases in flood damage due to the expansion of development within floodplains under the assumption that dikes would prevent future flooding (also known as floodplain infilling) (Diehl, 1983). In 2017 the District of Squamish undertook a comprehensive review of all the flood diking within the municipality and adopted a new goalpost to address sea level rise as part of the Integrated Flood Hazard Management Plan (DOS, 2017).

Another study initiated in May 1979, the Squamish River Estuary Management Study, was intended to develop a plan for the use of the estuary that would complement the settlement of the townsite of Squamish and optimize resource / habitat values while providing the long-term trade, development and energy requirements of the community and province (SEMP Recreation Work Group, 1982). The 1982 study did not specifically address the impacts of the Training Dike and it was not until the 1999 SEMP study that any specific directions were provided to allow for improvements for fish and wildlife.

In 2017, with the upgrading of the DOS Integrated Flood Hazard Mapping the upper section of the Training Dike (just below Fisherman's Entrance access way) was incorporated as flood protection and was included in the District of Squamish Integrated Flood Hazard Management Plan (DOS, 2017) (Figure 5).

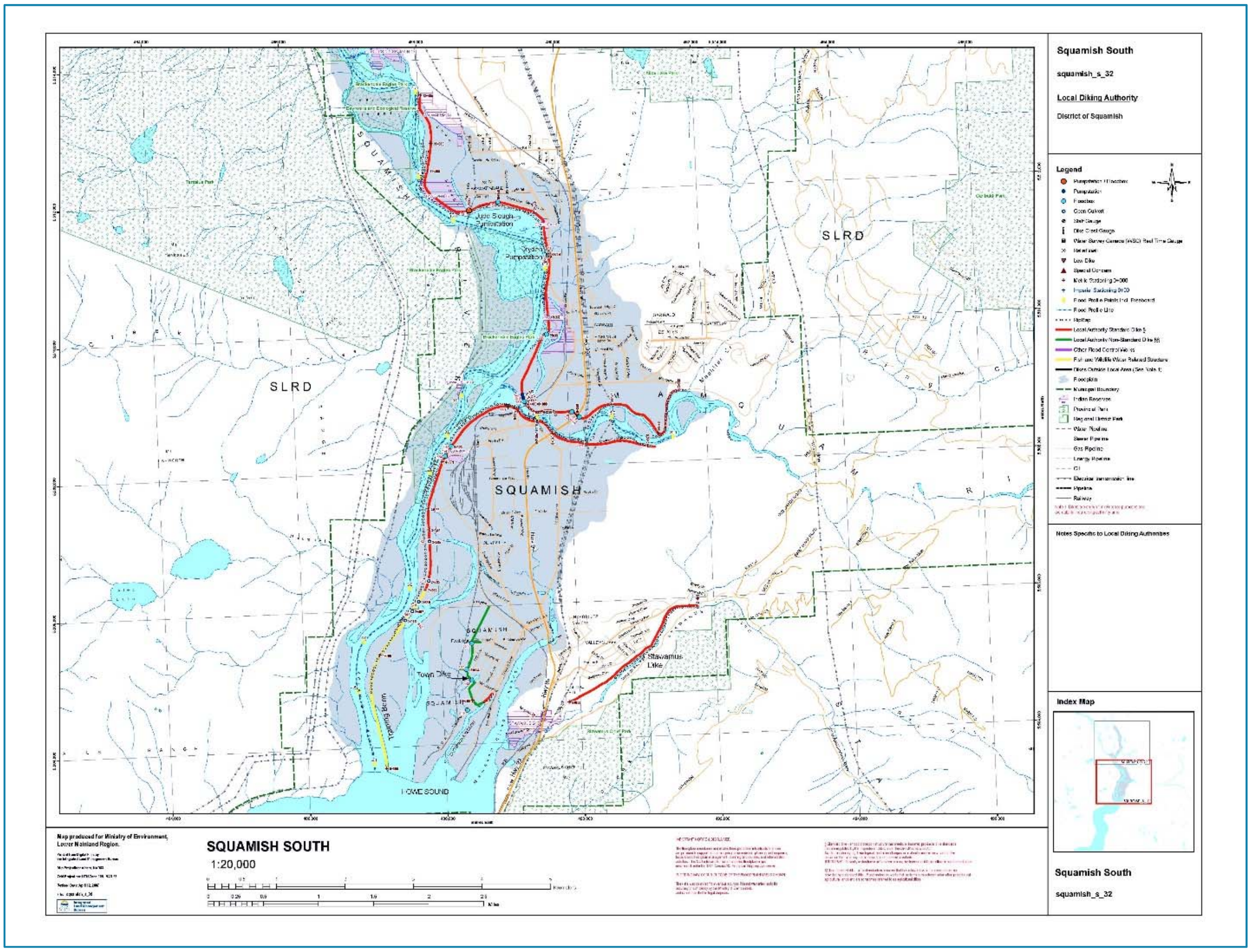


Figure 5. District of Squamish Integrated Flood Hazard Mapping

(showing in red the DOS flood dikes)

SQUAMISH TRAINING DIKE AND CULVERT INSTALLATIONS

The Training Dike, as noted earlier, was constructed in the early 1970s to confine the Squamish River to the western bank to enable the construction of a coal port, soon became a remnant of a non-existent industrial expansion. Even thought it was determined in 1972 that a coal port would never be approved, the 5 km Training Dike remained as a physical legacy that effectively prevented the mixing of freshwater flows from the Squamish River from mixing with the brackish waters of the Central Estuary.

Over time the Training Dike primarily functioned as an access point for recreational activities (refer to Appendix 1 for expanded description of recreation activities).

At the time the Training Dike was initially constructed in the early 1970s only two culverts were installed. They were located approximately 1.5 km upstream to allow the exchange of around 1.5 cms of flow between the river and the Central Estuary. Within a few years these culverts were fully blocked and no meaningful flow and water exchange between the Squamish River and the estuary could occur (A. Machel, pers. comm., 1994). Between 1994 and 2005 four additional culvert crossings were installed with oversight from Fisheries and Oceans Canada to provide improved water exchange and access for salmonids and other fish as well as wildlife; otters have been observed on more than one occasion moving through the culverts.

In 2006 discussions regarding the removal of the Training Dike were held between Fisheries and Oceans Canada, District of Squamish, and the Ministry of Environment. A decision was made at that time to not remove any portion of the Training Dike due to conflicts with other interests in the area. As a result of the decision to leave the Training Dike in-tact there was recognition of a high restoration potential for installing additional culverts. This resulted in the decision to add three more culvert crossings in 2007 at strategic locations along the Spit to maximize the opportunity for juvenile fish passage (Figure 6).


1994 Culvert Installation (photo credit: M. Foy)


2007 culvert installation (photo credit: E. Tobe)

An initial study was commissioned by the SRWS in 2013 with funding from the Pacific Salmon Foundation (PSF) to examine the movement of juvenile Chinook salmon in Howe Sound. This was expanded in 2015 to focus on usage within the Squamish Estuary. This study (which is more fully discussed in Appendix 1) indicated the culverts may be restricting access to the juvenile fish from the river into the estuary.

Preliminary Impact Assessment of Proposed Port Development in the Mamquam Channel and Rail Yard Expansion in the Squamish Estuary

"Physical characteristics of Squamish Estuary is either floodplain or alluvial fan and is unpredictable and unsuitable for urban development. There is recognition that the land is hazardous and subject to dramatic change (such as was experienced during the 1921 flood in which the Mamquam River changed direction of flow). Soil properties are unfavourable and would require major reclamation or special protective designs. Costs would be high and impractical. Records indicate the village of Squamish has been inundated to a depth of about 5' once every 16 years and has suffered flooding to some degree at least every 7 years." Department of the Environment, December 1972.

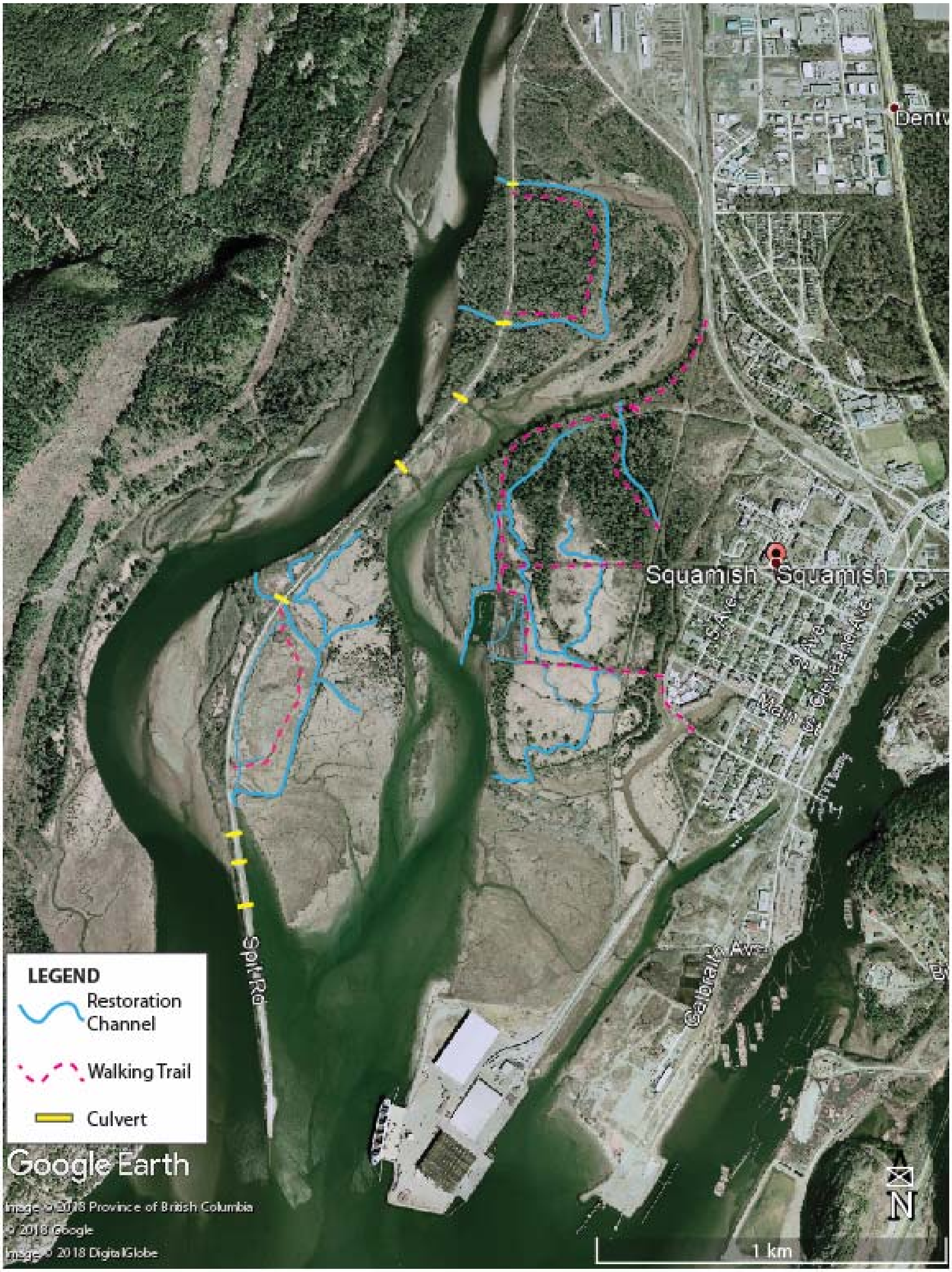


Figure 6. Estuary Restoration Sites, Trails, and Culvert Crossings

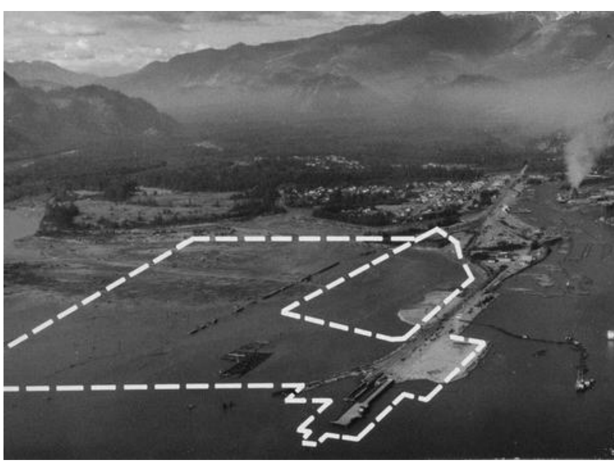
LAND USE AND LAND MANAGEMENT STRATEGIES IN THE SQUAMISH ESTUARY

There are differing accounts of when the first European settlers arrived in the Squamish area. In their report "The Squamish River Estuary Status of Environmental Knowledge to 1974", Hoos and Vold indicated that in 1873 surveying began for a cattle trail between Squamish and Lillooet, an in the following year the first Squamish land acquisition was made, with the purchase of 400 acres for a cattle pasture. While by 1875 this proved to be a poor route for cattle the first actual settlers arrived in 1877 for the purposes of logging Douglas fir and Sitka spruce and from that time onwards major changes were made to alter the natural system (Hoos and Vold, 1975), not to mention displace the Squamish Nation population. As part of the vision by the town of Squamish to be an industrial hub the opening in 1912 of Woodfibre Mill was followed in 1962 with the Weldwood sawmill (which was acquired by Interfor in 1995). This was followed in 1965 with the construction of the FMC Chlor Alkali Plant, which produced caustic soda (sodium hydroxide), hydrochloric acid, and chlorine for the pulp and paper industry.

History of FMC Chlor-Alkali Plant:

Constructed in 1965 and operated by FMC until 1986 when Canadian Occidental Petroleum (CanadianOxy) purchased the site. This in turn was sold in 1988 Nexen. In 1989 Nexen commenced remediation of the site as it was discovered to contain numerous hazardous materials including plumes of mercury that extended into the sediments of the Mamquam Blind Channel and Cattermole Slough. In 2004 the District of Squamish acquired the site as part of the Squamish Oceanfront Development Corporation (SODC). In February 2016 the DOS sold the lands to Newport Beach Developments (Matthews Southwest and Bethel Land Corporation).

Another major development along the waterfront was the construction in 1972 of the deep-sea port facility: the Squamish Terminals (a Norwegian owned company). With their history tracing back to the 1960s, the Squamish Terminals is serviced via an extension of the BC Railway along the "Spur Line". This railway connection to the north has allowed for the expansion of pulp production capacity in BC and the opportunity for the development of a deep-water port.



Uncredited photo prior to construction of Squamish Terminals and Squamish Training Dike (circa 1965). Note construction of former FMC Chlor-alkali / Nexen lands on right

In 1962 Weldwood established a 21.17 ha sawmill on the Mamquam Blind Channel to mill wood harvested in Tree Farm Licence 38 (TFL 38). The mill was purchased in 1995 by International Forest Products (Interfor) who ran and operated up to 185 workers until the recession hit and heavily impacted lumber exports. The mill closed down in October 2004.

In the early 1970s, BC Rail was looking to provide a coal port expansion in the Squamish Estuary and in 1970 began construction of a Training Dike to confine the Squamish River to the west side of the estuary. However, as the government of the day failed to take into consideration the concerns from Squamish Nation and the local community as to whether the estuary should be developed for a coal port facility, it never reached fruition. The site of the coal port was abandoned to Prince Rupert.

> "Only in recent years have we begun to realize that estuaries are amongst the most critical and productive of the world's ecosystems"
> Paish, 1972.

In May 1979 the Federal and Provincial governments initiated the Squamish Estuary Management Study to develop a plan for the use of the estuary that would optimize resource use and preserve habitat values while providing long-term trade, development, and energy requirements of the community and province (SEMP Recreation Work Group, 1982).

Purpose of 1981 Squamish Estuary Management Plan Habitat Work Group:

Phase 1

- Compile and analyze existing data regarding habitat types, and their use by fish and wildlife;
- Delineate present terrestrial, intertidal, and aquatic habitat zones;
- Identify marine, brackish and freshwater areas;
- Identify terrestrial, emergent, and submerged plant associations;
- Identify primary productivity indices;
- Identify benthic invertebrate populations;
- Identify natural rivervine and oceanographic factors affecting the physical substrate;
- Describe the fishery resource base and its commercial and recreational values;
- Describe the level of habitat utilization and the distribution and periodicity of use by fish stocks (where relevant);
- Describe the wildlife resource base and its commercial use;
- Describe the level of habitat utilization and the distribution and periodicity of use by wildlife populations (where relevant);
- Identify areas formally designated for fish and/or wildlife protection;
- In conjunction with Land Use Work Group identify past land use practices and industrial and urban developments and activities which have decreased or increased the productive capacity of the aquatic fisheries environment, and of terrestrial and aquatic wildlife environments;

- Identify information gaps; and
- Identify current problems and conflicts (habitat / fisheries / wildlife).

Phase 2

- Identify habitat maintenance, restoration, and enhancement opportunities;
- Outline habitat requirements for major species or groups, identify levels of habitat-oriented dependency, food chain relationship, water quality for fish stocks; and
- Outline habitat requirements for major species or groups, identify the level of habitat-oriented dependency in terms of food, space, water quality, for wildlife populations.

Phase 3

- Describe integrated resource use potentials for all major habitat types; and
- Make recommendations concerning opportunities for the maintenance, restoration, and enhancement of habitat.

The 1982 Plan also resulted in the formation of the Squamish Estuary Coordinating Committee (SECC) whose purpose was to link government, industry and private interests in guiding land and water uses in the Squamish Estuary. However, the SECC had no representation from Squamish Nation or the community.

In order to modernize the plan, the SECC brought forward a revised plan in 1992. However, this plan, while endorsed by its members, was never implemented and the estuary continued to be managed under the 1982 Plan. From 1992 until 1998 there was large scale public engagement that allowed for broader representation and decision making, including input from Squamish Nation, the community, and other interest groups.

In 1999 a multi-jurisdictional plan was signed off by Environment Canada, Department of Fisheries and Oceans Canada, BC Rail Properties, District of Squamish, and Ministry of Environment and Lands. The revised plan included 579 ha for conservation, 350 ha for development, and 8 ha for further planning assessment along the upper Mamquam Blind Channel. Within the conservation lands, 30 ha of environmentally sensitive lands were designated for transfer to Squamish Nation as part of Site “A” (Figure 7).

With the signing of the SEMP two new committees were struck: the Squamish Estuary Management Committee (SEMC) and the Squamish Estuary Review Committee (SERC). The Squamish Estuary Management Committee took over from the previous SECC and consisted of broader representation from interest groups and stakeholders. The function of the SEMC was intended to coordinate planning and management of environmental and developmental activities within the SEMP boundaries.

The Squamish Estuary Review Committee was created as a regulatory body and had representation from Environment Canada, Fisheries and Oceans Canada, Ministry of Environment, Squamish Nation, and District of Squamish. The intent of SERC was to screen project proposals, direct them to the appropriate review process, monitor their progress, and undertake technical environmental reviews of proposed projects not subject to other environmental review processes within the SEMP boundaries.

Starting in 2005 the SEMC was instrumental in providing input to the Province regarding the creation of the 673 ha Skwelwil'em Squamish Estuary Wildlife Management Area (WMA). The vision of the WMA was to maintain and restore the productivity of the fish and wildlife habitats in the estuary. Important habitats for species at risk, water fowl and migratory birds were to be given the highest management priority followed by the protection and restoration of fish and wildlife habitats. An integrated management approach involving stakeholders and all levels of government was to be used to achieve the goals and strategies outlined in this management plan (Figure 7) (WMA, 2007).

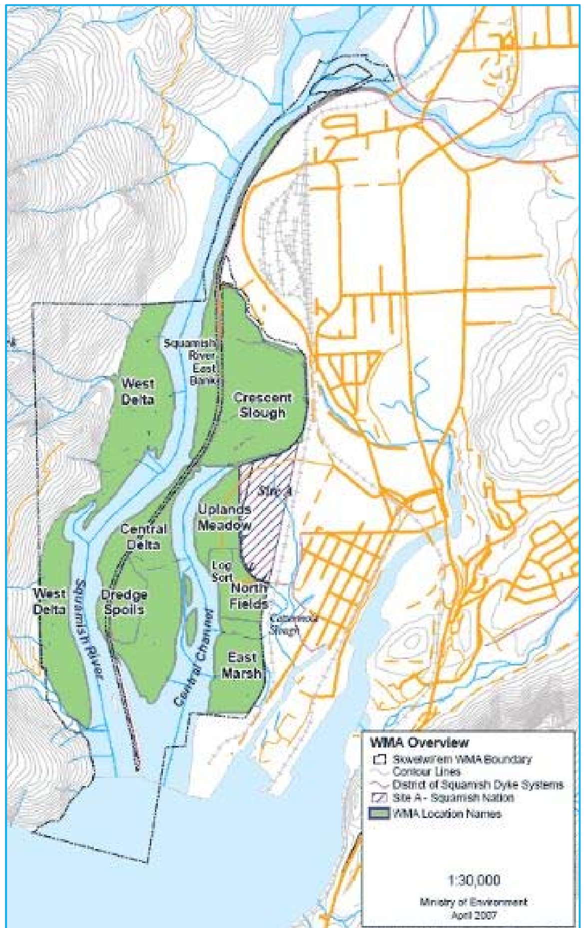


Figure 7. Skwelwil'em Wildlife Management Area

At the time the WMA was created in 2007, responsibilities for the overall management of the estuary and the Training Dike were discussed with the District of Squamish. The Province was to be responsible for management and protection of natural values in the WMA. The District of Squamish was to manage the Training Dike as follows:

- DOS to conduct emergency repairs and maintenance of the Dikes as necessary.
- DOS to add no further soil for improvement of mowing on the dike. Allowance to be made for portions of the flood dikes to repair the mowing surfaces.
- Any soils for aforementioned purposes must have a known and approved history.
- DOS to mow flood dike up to two times per year as far down the slope of the dike as the mower will reach. To be scheduled in consultation with DOS Environmental Coordinator for the benefit of birds and wildlife.
- The DOS to mow the majority of the Training Dike once per year one mower width down from the top of the dike's horizontal surface. Generally, no mowing of the Training Dike south of, or downriver of, the gate near the wind sports area

(Spit). This area will be left wild or only occasionally mowed due to excess build up of vegetation.

- Generally, no vegetation will be planted along the slopes of the Dikes and seeding will occur from the adjacent vegetation.
- The road surface on the top of the dike will be, over time, managed to a width of about 2.5 vehicle widths with two small pullouts or parking areas located at the trailheads. (WMA, 2007)

The boundary of the Squamish Estuary Management Plan (Figure 2) includes the entire Wildlife Management Area, Site “A”, Site “B”, Cattermole Slough / Bridge Pond, and the entire Mamquam Blind Channel. The land uses identified in the 1999 SEMP are in the process of being updated through documents such as the DOS Official Community Plan (OCP) and Marine Area Protection Strategy (MAPS). As part of the original 1999 SEMP only the WMA and Site “A” were to be protected as conservation lands (Figure 8).

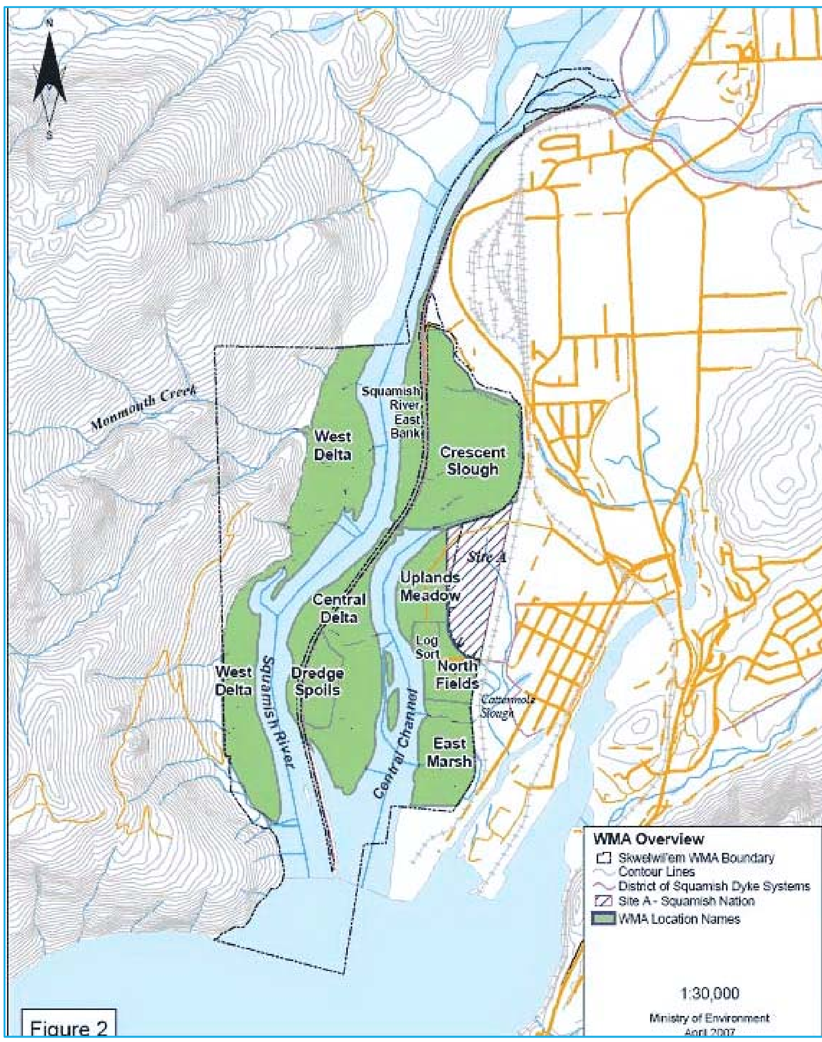


Figure 8. Skwelwil’em WMA boundary (WMA 2007)

In 2007 the Squamish River Watershed Society in partnership with The Land Conservancy of BC helped to secure 7.18 hectares of lands (DL 4265) along the Mamquam Blind Channel (Figure 9). These lands were then given over to the DOS for management and protection in order to preserve the ecological values.

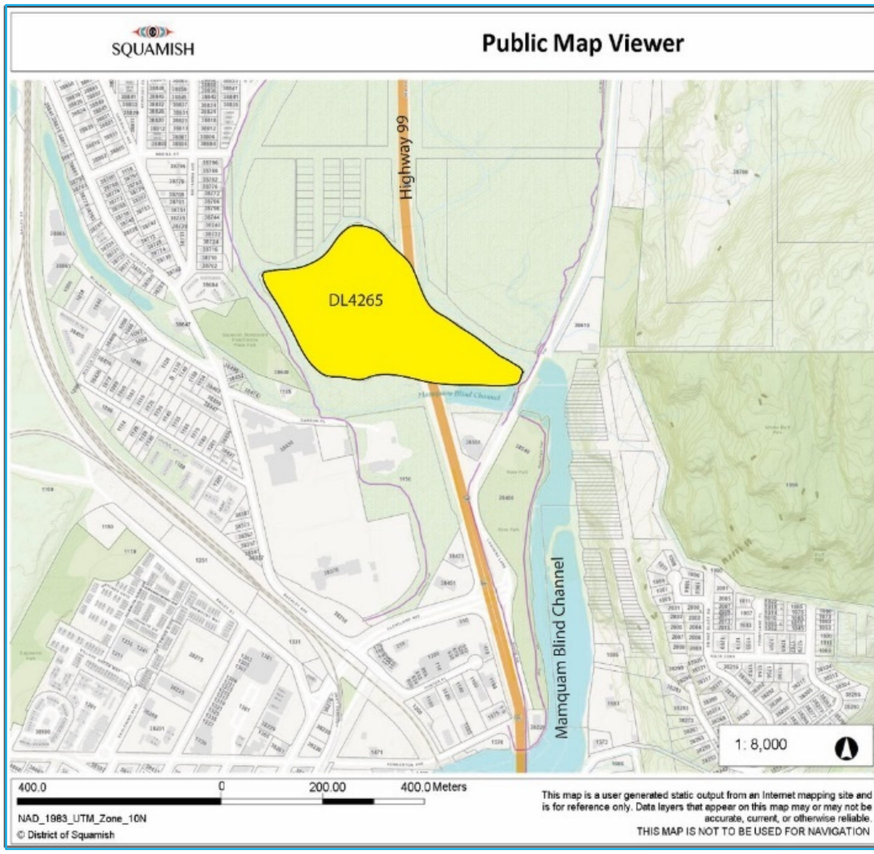


Figure 9. Location of DL 4265

in 2009 the Nature Trust of BC acquired 5.3 hectares of previously unprotected estuarine lands adjacent to the WMA alongside the Cattermole Slough / Bridge Pond to the east of the Transportation Corridor (Figure 10). Their intention on purchasing these lands were to manage these lands in a similar manner to the WMA.

Furthermore, Squamish Nation is in the process of finalizing a land management strategy for Site "A" that would also be consistent to the WMA.

However, there remains significant estuarine habitat with no conservation or protection status including all the areas outside the TNT lands along the Cattermole Slough / Bridge Pond, and the remaining Mamquam Blind Channel outside of DL 4265.

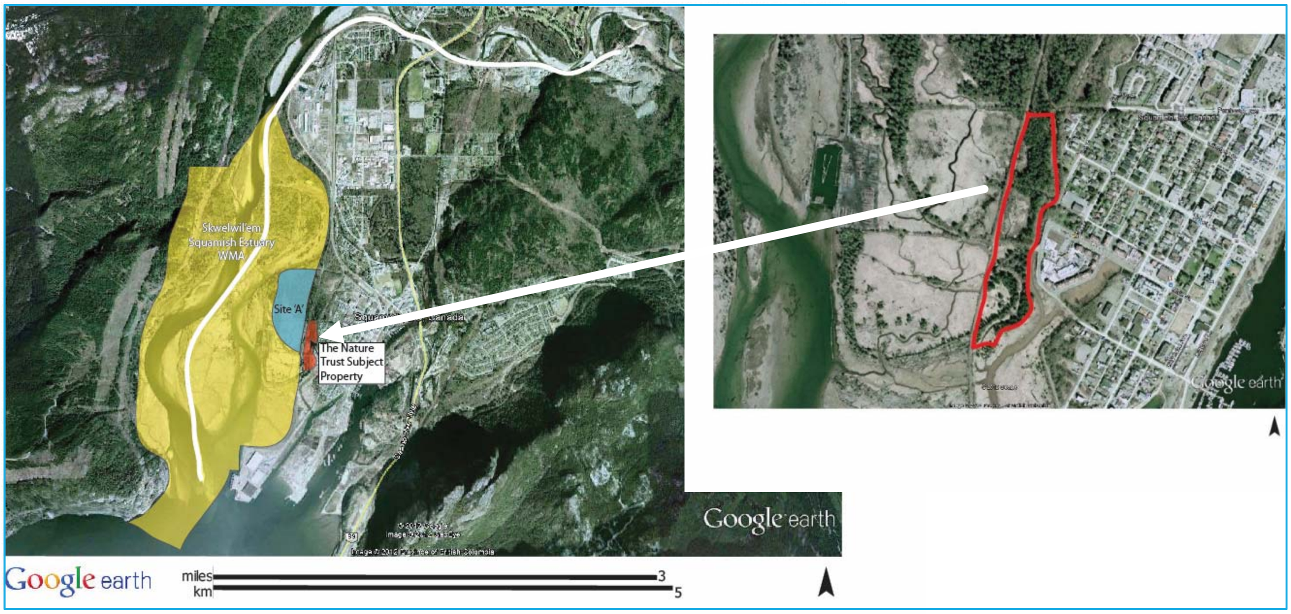


Figure 10. Nature Trust of BC property

SECTION 3: CONCLUSION

The Squamish River Estuary Overview Report was intended to provide a detailed summary of data and research on the Squamish Estuary. Historical narrative from Squamish Nation goes back thousands of years. Records from the first European settlements and their efforts to cultivate and ultimately develop the Squamish Estuary are well documented. Industrial development and expansion of the townsite from the 1970s onwards has dramatically altered the characteristics of the estuary resulting in over 50% loss to development of the townsite and industrial expansion.

From the 1980s until 1999 strategic management plans were developed to provide a balance between industrial, economic, and environmental considerations. These resulted in the 1999 Squamish Estuary Management Plan followed by the 2007 Skwelwil`em Squamish Estuary Wildlife Management Plan. Ongoing management plants for Site “A”, the Nature Trust of BC lands, and DL 4265 are still in the works. As well, the DOS initiated Marine Area Protection Strategy is just being developed.

No document can adequately capture all the history on the Squamish Estuary, but the hope is this Report will provide background information that will assist with future decision-making processes, further scientific studies, and hopefully an overall understanding and appreciation for the importance and function of the Squamish River Estuary.

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APPENDIX 1: RECREATION, RESTORATION, AND FUTURE OPPORTUNITIES

RECREATION

The usage of the waterfront in Squamish has changed dramatically since the 1950s and the population of Squamish has steadily increased over the following decades. The most apparent changes are to the estuary with the expansion of the townsite and industrial sites, dikes, rail lines and roads. It was not until the early 1980s that recreation was even a consideration but as part of the Squamish Estuary Management Plan, in 1982 the SEMP "Recreation Work Group Final Report" was published (SEMP Recreation, 1982).

> "The town of Squamish is not and will not likely become a major focus for tourism or regional recreation." (SEMP Recreation, 1982)

During the 1980s the main recreation user groups included campers, nature observations, hiking and walking, some small water craft, hunting, and fishing. Access to the estuary predominantly was gained either along the Training Dike or through the downtown to the west side of the former BC Rail Spur Line (Figure 6).

In the mid-1980s local enthusiasts access the south end of the Training Dike to go wind surfing and enjoy wind sports activities. 1988 the Squamish Windsports Society (SWS) became registered as a non-profit organization in order to secure access to the southern tip of the Training Dike for recreational windsurfers. Today the SWS hosts windsurfers, kite surfers, and spectators. Membership from the SWS has participated on the SEMC an provided valuable input in the creation of the 2007 WMA. The SWS has entered into an agreement with the District of Squamish (DOS) granting SWS the authority to manage and operate a windsurfing facility at the end of the Spit annually between mid-May and mid-September, which was recognized as being compatible to minimally impact waterfowl and migratory bird values (WMA, 2007). As part of the agreement with the DOS and Province, wind sport activities are confined to the southern end of the Spit.


Windsurfing at the Spit

The Squamish Estuary has remained an important site for nature lovers and bird watchers. Since the early 1970s local wildlife enthusiasts have participated and late conducted monthly bird counts at various locations throughout the estuary. Detailed records from 1991 onwards can be found on the Squamish Environment Society's website[3].

Around 1999 the Squamish Estuary became recognized nationally by the Canadian Wildlife Service as an Important Birding Area, with formal caretakers overseeing annual reporting around 2006. The focus of IBA's allows the monitoring of birding sites of particular importance for habitat species at risk and of concern[4]. An agreement was adopted within the 2007 Skwelwil'em Squamish Estuary Wildlife Management Plan identifying the wind sports season from mid-May until mid-September in order to reduce disturbance to waterfowl and migratory birds.

Recreational fishing has remained strong in the Squamish Estuary as per the provincial fishing guidelines. And up until 2006, hunting was permitted annually from October 1 to January 31 for hunting of waterfowl (photo to right). However, in 2006 the District of Squamish adopted a bylaw to prohibit the discharge of firearms within municipal boundaries (DOS Firearms Bylaw No. 1946, 2006).

From 1970 until the early 2000s the former dredge spoil site (Figure 1) was popular for motorized off-road sport activities: the removal of the brownfield back into functional estuary in 2003 displaced that activity with more passive recreation pursuits such as bird watching, kayaking, and hiking.

The importance of recreation within the Squamish Estuary was included in the 2007 WMA in recognition of the importance of recreation to the community of Squamish. While the WMA did not focus on recreation values it allowed provisions to allow existing walking trails along with some expansion and maintenance (Figure 7). While the WMA allowed for hunting and fishing the DOS by-law still prohibited the discharge of firearms within DOS boundaries. The other provisions within the WMA for recreational pursuits focused on water-based activities including canoeing, kayaking, paddle boarding, and the aforementioned wind sports. While the WMA recognized motor vehicle access could result in potential threat to fish and wildlife values within the WMA, this is governed under Navigable Waters Protection Division of Transport Canada which does not restrict access.

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[3] SECS bird counts: http://www3.telus.net/djlassmann/bird_counts/Squamish_Counts.htm
[4] https://ibacanada.ca/site.jsp?siteID=BC023

At any time, anyone who observes any activity that may violate, threaten, or impact fish and wildlife values they are encouraged to contact the appropriate authorities to report their concerns. Contact information for municipal, provincial, and federal departments can be found as follows (subject to any changes):

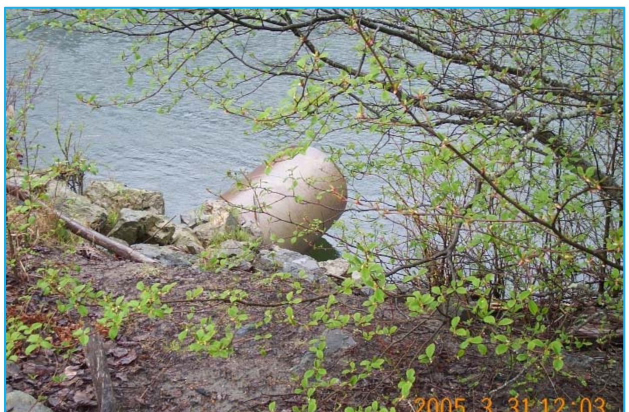
- District of Squamish By-law department: 604.815.5067
- Federal Fisheries Observe, Record Report hotline: 1.800.465.4336
- Provincial Report all Poachers and Polluters hotline: 1.877.952.7277

With the increased population moving to Squamish and a with a DOS slogan: "Hotwired for Adventure" there will likely continue to be increased pressure on the estuary and naturalized areas in and around Squamish. As such, there will be an increased need in the near future for strategies and management plans to ensure expanding recreation pressures do not unduly impact the natural environment and estuarine habitat.

RESTORATION

Governing agencies including DFO and MFLNRORD have held an interest in the Squamish Estuary, an in particular, the Training Dike and the impacts it has in estuarine processes and fish habitat. On-going monitoring from the original construction identified significant impacts on fisheries, especially usage by juvenile salmonids. Anecdotally the pink salmon runs, which numbered in the hundreds of thousands, collapsed in the early 1990s at the same time the Training Dike was completed. It was not until 2001 that the pink salmon runs were observed to once more be in the thousands,

The creation of the 1999 SEMP and 2007 WMA plans included improvements to fish habitat within the Central Estuary for salmonids including removal of the former dredge spoils pile (Figure 1), installation of culvert crossings along the Squamish Training Dike, reconnection of tidal channels on the western, central, and eastern deltas, removal of the former dredge spoils pile (south end of the Training Dike), and restoration of the former West Barr log sort. Much of these works were completed between 1994 – 2017.



Culvert crossing (C3) on Training Dike (E. Tobe)

The restoration efforts involved adaptive management in the form of modifications to the physical works to improve the outcomes for fish and wildlife. The success of the projects was much in part to the expertise of the fisheries biologists and engineering staff provided by DFO and Squamish Nation and the consistency in staff who could incorporate long-term goals in a realistic time frame that spanned over 20 years.

Based on the literature review of the previous 50 years, there is little doubt the expansion of the townsite, construction of industrial sites such as the former sawmill, chlor-alkali plant, log-sorts, and Training Dike, as well as the Squamish Terminals with the only active deep-sea port has dramatically impacted the function of the estuary.

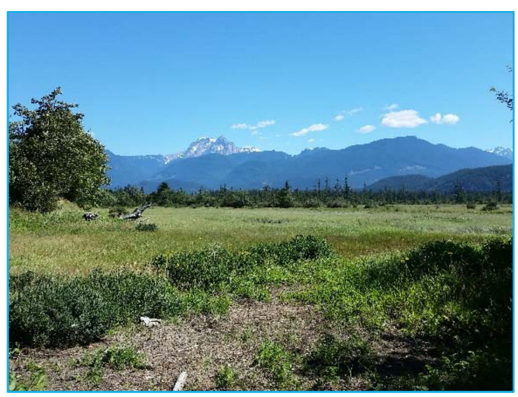
Little research has occurred in recent years but the studies in the 1970s and 1980s have provided extensive background information on the flora, fauna, hydrology, and geology of the estuary. Conversations with members of Squamish Nation have added to the knowledge base and allowed discussions to proceed on mechanisms by which the estuary can be improved from a fishery, hydrologic, and overall functional standpoint.

In order to offset impacts from development the Squamish River Watershed Society has undertaken numerous projects to restore large portions of the Squamish Estuary to improve fish passage, wildlife values, tidal flows, as well as incorporate interpretive trails and educational programs. Table 1 summarized the major projects completed at the date of this report being published.

Recent studies by the SRWS have indicated the culverts along the Training Dike are restricting access into the estuary by juvenile salmonids as they migrate down the Squamish River due to sizing and location. This has lead to collaboration between local NGO's, First Nations, government, industry, recreation, and educational partners to examine innovative approaches to improve the estuary for fish and wildlife.

Restoring the former Dredge Spoil Site (current Chelem / Seagrass Trail site) (photos by E. Tobe):

August 31, 2003



July 12, 2018

Table 1. Restoration activities in the Squamish Estuary

Date	Location and Details	Total Area Restored
1995 – 1999	Installation of Culverts #1 & #2 (north end of Training Dike)	
1999	Tidal Channel Connector at Crescent Slough: Connector channel to Culverts 1 & 2 (1307 m length x 2.0 m width x 1.2 m depth); walking trail (1000 m length)	2,600 m^2
2001 – 2005	Dredge Spoils Site: Removal of dredge spoils site (5,000 m^2) and restoration of tidal channels along perimeter (570 m length, 2.4 m depth, 0.75 m width) and adjacent to dike road (85 m length, 1.0 m depth, 0.6 m width); construction of walking trail (300 m length); installation of culvert at north end of dredge spoils site and weir/connecting channel at south end of dredge spoils site with discharge into Central Estuary; construction of 2 pedestrian bridges; planting of over 1,000 sedge plugs; planting of over 500 native riparian shrubs	15 hectares
2002 – 2003	Tidal channel and Marsh Restoration along East Delta (by log-sort): restoration of tidal channel, construction of bridge, and planting of over 500 native riparian shrubs	5,000 m^2
2003 – 2004	East Marsh: Tidal channel connectivity to allow north/south flow and reconnect tidal channel for rearing habitat; 250 native riparian shrubs planted; site adjacent to Blue Heron Trail	2,500 m^2
2004 – 2006	East Delta Tidal Channel Connection in Site “A”: construction of 1,000 m length intertidal habitat; revegetation of sedges, Sitka spruce, and native riparian shrubs, construction of bridge	3,000 m^2
2006 – 2007	West Barr Road Culvert Crossing: Installation of 500 m length tidal channel, two bridges, 40’ x 36” culvert, 500 riparian trees and shrubs	3,500 m^2
2007 – 2008	Culvert installation along Spit Road: Three steel 36” culverts were installed spaced 200 m apart along the Spit Road	
2008 – 2010	Installation of Trash Racks: Trash Racks installed on river side of culverts at crossing number 1, 2, 3, and 5	
2015 – 2016	West Barr Log Sort Restoration: Conversion of brown field site back into functional estuarine habitat with three tidal channel connections; planting of over 1,000 sedge plugs; planting 700 eelgrass shoots; over 2,000 riparian native shrubs; four bridges; deactivation of access logging road;	5.8 hectares

Restoration of former log sort.
March 13, 2017. Photo by E. Tobe

FUTURE OPPORTUNITIES

At present, in 2018, the Squamish River Watershed Society, in partnership with DFO and Squamish Nation, are hoping to improve fish access between the Squamish River and Central Estuary by replacing culverts along the Training Dike with clear-span bridges and examining the realignment of the Spit to open the southern portion of the estuary and re-establish over 77 hectares of accessible estuary to fish and wildlife. The location of the culvert upgrades will be dependant upon hydrologic and sediment modelling (currently being undertaken) and discussions with the DOS and governing agencies. Installation of uni-directional flow mechanism (west to east) across the CN Spur Line to reconnect the waters from the Site "A" back into upper Cattermole / Bridge Pond are also being examined as this could dramatically improve water quality and fish habitat.

As with any large-scale project, discussions will be undertaken with full consultation between government agencies, Squamish Nation, Squamish Terminals, Squamish Windsports Society, and local conservation and business interests. The contents of this Report will hopefully provide a good basis by which decision making will be made.

Drone video of south end of Training Dike and Spit (image courtesy of Coastal Photo Studios)

APPENDIX 2: BIOLOGICAL PROCESSES OF THE SQUAMISH ESTUARY

FISH DISTRIBUTION AND BENTHIC INVERTEBRATES IN THE SQUAMISH ESTUARY

There is limited research data available in recent years on fish usage within the Squamish Estuary with the majority of studies being undertaken in the 1970s and 80s. In 1972 a Task Force was assembled by the Federal-Provincial Fisheries Service as part of the Squamish harbour development to study how the estuary functions and the respective habitat values. Reports such as the "Preliminary Impact Assessments of Proposed Port Development in the Mamquam Channel and Rail Yard Expansion in the Squamish Estuary" (DOE, 1972) spearheaded much of the research on fisheries for the next two decades.

Preliminary Impact Assessments of Proposed Port Development in the Mamquam Channel and Rail Yard Expansion in the Squamish Estuary. Department of Environment. December 1972

In October 1972 the Department of Environment prepared a report entitled "Effects of Existing and Proposed Industrial Development on Aquatic Ecosystems of the Squamish Estuary". This report, based on studies undertaken between April and August 1972, assesses the impact of proposed port development on the fishery resource of the Squamish River system and upper Howe Sound. Particular emphasis was directed toward determining ecological implications of constructing unit and bulk loading port facilities in the central portion of the estuary. The report documented the existence of a complex estuarine food web leading from primary producers (phytoplankton, algae, and marsh vegetation) through primary consumers (zooplankton and bottom feeding invertebrates) to fish. It further indicated that the central portion of the estuary was highly productive, that estuarine production in the westerly portion was endangered by the recent river training, and that productivity in the easterly sector had been reduced by previous industrial development. On the basis of this relatively short-term study it was recommended that "industrial development be confined to those portions of the Squamish delta which do not contribute to estuarine productivity". The scope of the study did not permit and evaluation of the broader environmental, social, land use, and economic implications which are an integral component of comprehensive planning.

The research mentioned above was undertaken in 1972 by Goodman and Vroom to sample juvenile fish on a weekly basis from April until August (Goodman, 1972). The overall objective of the Task Force was to find a design which would maintain adequate delta conditions for juvenile salmonids. This study has become the reference point for fish usage and distribution in the estuary.

In later years, in 1975, Hoos and Vold concluded that the central delta area was the most favourable habitat for juvenile salmonids in the river estuary, while herring, although not as abundant as in previous years, frequented the east delta channels. Fish distributions were directly correlated with the habitats of their major food sources: amphipods, in the case of salmonids, and mysids for herring (Hoos ,1975).

In 1978 Levy and Levings published “A Description of the Fish Community of the Squamish River Estuary, British Columbia: Relative Abundance, Seasonal Changes, and Feeding Habits of Salmonids”. The document is a summation of the fish study they undertook, sampling from October 1975 until September 1976 at key locations (Figure 11) in the estuary using beach seines, gillnets, and tidal creek enclosures (Levy, 1978). The report concluded that juvenile salmonids used the estuary during spring and summer months and the salmonids in the estuary primarily fed on marine crustaceans and insects. They also found as part of the study there was no evidence of diet segregation between Dolly Varden and cutthroat trout and no marked differences in relative abundance and distribution of juvenile salmonids when compared with surveys from the 1972 Goodman and Vroom study, even though major changes had occurred to the estuary including the construction of a river dike.

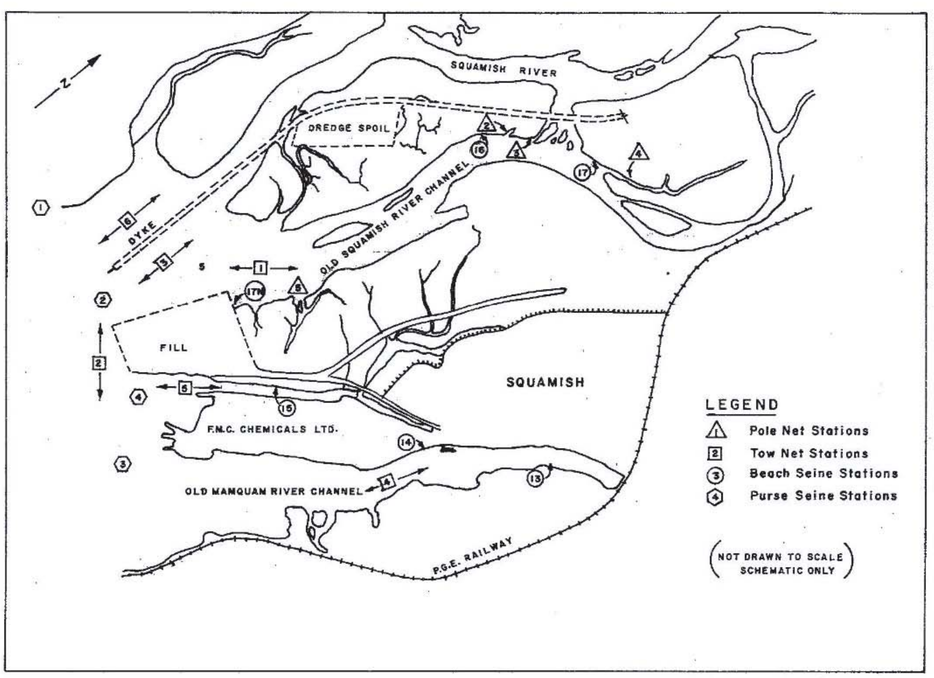


Figure 11. Squamish Estuary Sampling Stations, 1972 (Stanhope, 1972)

Some of the findings by Levy and Levings included a comprehensive survey of the fish community of the Central Basin from 1975 to 1978 which divided the key species they caught into two groups: permanent residents and temporary residents (refer to Table 2) (SEMP Habitat Work Group, 1984).

Table 2. Fish distribution of permanent and temporary residents (SEMP Habitat, 1984)

Permanent Residents		Temporary Residents	
Staghorn sculpin (most abundant from June – Sept)	*Leptocottus armatus*	Herring (no spawning noted)	*Clupea harengus*
Starry flounder	*Platichthys stellatus*	Chum	*Oncorhynchus keta*
Surf Smelt	*Hypomesus pretiosus*	Coho	*Oncorhynchus kisutch*
Cutthroat trout (found in all age classes all year)	*Salmo clarki*	Chinook	*Oncorhynchus tshawytscha*
Dolly Varden char	*Salvelinus malma*	Spiny dogfish	*Squalus acanthias*
		Snake prickleback	*Lumpenus sagitta*
		Prickly sculpin (caught various times of year; likely spawned in estuary	*Cottus asper*
		Shiner perch (seasonally abundant Sept – Oct)	*Cymatogaster aggregata*
		Threespine stickleback	*Casterosteus aculeatus*
		Pink salmon	*Oncorhynchus gorbuscha*
		Eulachon	*Thaleichthys pacificus*
		Sand lance	*Ammodytes hexapterus*

Another report to summarize available data on Provincial fisheries resources on fresh water species was conducted in 1980 by the Provincial BC Fish and Wildlife Branch and included studies on rainbow trout/steelhead, coastal and sea-run cutthroat trout, Dolly Varden char, three-spined stickleback, sculpin, and lamprey (Peatt, 1980). In this study the conclusions reached were that little was known about the actual distribution of trout and char in the Squamish estuary and based on previous studies examining catch size, the old Squamish River channel (middle arm) provided the most favourable habitat for juvenile salmonids. The study also referenced personal communications with J. B. Reynolds and Brian Clark stating that cutthroat trout were present in the Central Estuary throughout the year and that cutthroat and Dolly Varden were thought to be most abundant in May when Chinook and pink salmon juveniles can be found in the estuary. In 1978 and 1979, as part of his research, Clark noted the presence of steelhead juveniles in Monmouth Creek (Peatt, 1980).

From 1979 until 1981, as part of the Squamish Estuary Management Planning processes, a Habitat Task Force was created with representation from the Province and Federal fisheries departments. The Habitat Task Force published the Squamish River Estuary Management Study in 1982, a document to develop management plans for the lower Squamish River and Estuary. This Study included a section specific on use of the estuary by fish, both freshwater and marine species (SEMP Habitat Work Group, 1982). The Habitat Task Force relied heavily on the 1972 study by Goodman and Vroom and the work undertaken by Levy and Levings in 1978, which confirmed the largest densities of juvenile salmonids were found in the Central basin.

The 1982 SEMP Habitat Work Group publication indicated locations within the study area used for spawning salmonids were not well documented. Chum salmon were noted to spawn in a slough on the west side of the Squamish River approximately 1.6 km upstream of the delta (Figure 10). Pink spawning was observed on gravel bars in the Squamish River about 0.7 km downstream of the Mamquam River. Monmouth Creek was noted to accommodate spawning chum and coho salmon as well as steelhead.

As well, the publication noted the gravel patches located in the Central basin approximately 1.0 km upstream of the Training Dike culverts. These were thought to be used by spawning sea run cutthroat trout. As for the distribution of juvenile salmonids they were noted to coincide where amphipods and invertebrates were found to be abundant. Of particular note, the old Squamish River channel (stations 16 and 17 and pole net station 4 in Figure 11), appeared to provide the most favourable habitat for juvenile salmonids within the inner estuary.

Levings suggested the construction of the Training Dike reduced flushing of amphipods (Figure 10) from the Central area of the estuary and was responsible for the relatively high abundance in this area (Levy, 1978). The distribution of fish, especially juvenile salmonids, throughout the estuary appeared to be directly correlated with the presence of invertebrates. In 1978 Levy and Levings also observed the abundance of amphipods fluctuated in the Central Delta as sedge rhizomes and benthic algae changed seasonally. From November to March, when the standing crop of benthic algae was greatest, amphipods were about equally abundant in the two habitats. In spring and summer, amphipods were far more numerous under sedge rhizomes (Levy, 1978).

For chum, Chinook, and coho salmon the main food source appeared to be *Anisogammarus spp. Chironomids*, amphipods, stonefly nymphs, and other organisms were also observed along with Mysids which appear to be an important food item in chum salmon as were Mysids for Chinook (Goodman, 1972).

Amphipods (*Eogammarus confervicolus* and *Neomysis mercedis*) were observed to provide a major food sources of juvenile salmonids, herring, sculpin, and starry flounder.

The stomach contents found in juvenile Chinook consisted primarily of *N. mercedis*. Coho fed largely on *E. confervicolus* and *N. mercedis* (which, in turn, coincided with strong association of distribution of sedge); i.e. feeding on *N. mercedis* when sedge is absent. Dolly Varden appeared to feed on *Eogammarus confervicolus* and *Neomysis mercedis*, fish, and *Crangon sp*. Over 50% and 25% of the diet of cutthroat trout was made up *Eogammarus confervicolus* and *Neomysis mercedis* respectively. There appeared to be a shift in diet from *Neomysis mercedis* in summer to *Eogammarus confervicolus* in fall and winter (Levy, 1978).

Anisogammarus spp.

As part of the studies on invertebrate populations a total of 51 taxa of intertidal benthic invertebrates were observed by Levings on the Squamish River delta (1976 & 1980). Mostly the invertebrates were common amphipods, polychaetes, and dipteran insect larvae. The abundance and distribution of invertebrates was determined primarily by the salinity regime and distance from the river and secondarily by elevation and substrate type. Seasonal and spatial differences were noted in types of organisms collected in horizontal plankton tows on the delta.

Eogammarus confervicolus was found to be most abundant under sedge rhizomes or algal material but widespread over the entire delta. Levings suggested the construction of the dike reduced flushing of amphipods from the central area of the estuary and was responsible for the relative high abundance in this area. On the central delta the abundance of amphipods under sedge rhizomes and benthic algal changed seasonally. In his studies, from November to March, when standing crop of benthic algae were greatest, Levings observed amphipods were about equally abundant in the two habitats. In spring and summer, amphipods were far more numerous under sedge rhizomes (Goodman, 1972).

Levy and Levings (1978) found that while all species of salmonids from the Squamish River watershed (including the Cheakamus River) used the estuary to varying degrees it was Chinook salmon juveniles which relied the most on estuary habitat for extended periods of time. Chinook salmon residing in the Cheakamus River were listed as high by DFO. The Squamish River Watershed Society has worked with Fisheries and Oceans over the past number of years to restore critical estuary habitats. DFO remains committed to the design and development upgrades along the Training Dike and within the Central Estuary for the improvement of salmonid habitat. Aside from expected benefits to salmonids, many other estuary and near shore fishes such as herring are now benefiting from these completed works.

EXCERPT FROM SQUAMISH ESTUARY JUVENILE CHINOOK SALMON HABITAT USAGE SURVEY

(Lingard, 2018; InStream Fisheries Research Inc.)

1.0 INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) are the largest of the Pacific salmon and have a diverse life history. The Squamish River Chinook salmon population is part of the larger Georgia Basin management unit and classified as a summer run. A fall population has also established in the watershed. The fall population has been genetically linked to east coast Vancouver Island stocks (ECVI) and is thought to have arisen from hatchery supplementation programs that captured brood stock in Howe Sound in the 1990s and early 2000s. The summer population typically enters fresh water between June and August and spawns in late August (Schubert, 1993; Labelle, 2009). The fall population enters in late August to October and spawns between October and December.

Emigrations of juvenile Chinook salmon occur though out the year. Between January and June, a large emigration of recently emerged (30 to 50 mm fork length) fry occurs (Lingard et al., 2018). Beginning in mid-May through July, large sub-yearling (50-70 mm) and yearling (>70 mm) Chinook salmon leave the watershed (Lingard et al., 2018). Smaller groups of yearling and sub-yearling Chinook salmon have also been documented leaving the watershed in the fall (Melville and McCubbing, 2000).

Data pertaining to Chinook salmon abundance and productivity in the Squamish River watershed is limited. The Squamish First Nation has conducted an annual adult spawner index survey since the 1990s. Monitoring of juvenile Chinook salmon abundance on the Cheakamus River (a tributary of the Squamish River) for BC Hydro, as part of a water use planning (WUP) process, has been conducted since 2000 (Lingard et al., 2018). The Cheakamus Monitoring project is scheduled to end in 2018. Juvenile salmon abundance data in other parts of the watershed have not been collected limiting stakeholder understanding of stock status and watershed productivity.

In general, Chinook salmon populations have been in decline along the coast of British Columbia, Washington and Oregon since the 1980s (Slaney et al., 1996; Heard *et al,.* 2007). Poor ocean survival, over harvest and habitat losses have contributed to the reduction in abundance of Chinook salmon populations regionally (Slaney et al., 1996; Walters and Martel, 2004; Beamish et al., 2012). Salmon populations in the Squamish River have likely been impacted by many of these regional stressors as well as a significant loss in estuarine habitat a major flood in 2003, and a 41,000-litre caustic soda spill in the Cheakamus River in 2005 (McCubbing et al., 2005).

In 2005, the Pacific Salmon Foundation, in partnership with government agencies, Squamish Nation, and community stake holders, developed a “Squamish River Watershed Salmon Recovery Plan”. The Recovery Plan specifies target abundances for each species as well as mechanisms by which these targets would or could be achieved. Both hatchery supplementation and habitat restoration projects were implemented after the 2005 caustic soda spill to aid in the recovery of salmon populations. As of 2012, target abundances of Chinook salmon had yet to be obtained.

Since 1998, the Squamish River Watershed Society (SRWS) has been working in partnership with the Department of Fisheries and Oceans Canada (DFO) and the Squamish Nation to restore tidal channels and Chinook salmon rearing habitat. Estuarine habitats are important transition zones for Pacific salmon in both the juvenile and adult stages of their life history. Previous work suggests juvenile Chinook salmon use estuaries for varied periods of time extending from days to months. Complex interactions between factors such as prey availability and densities of other juvenile salmonids have been indicated as potential factors that influence patterns and duration of estuary habitat usage in Chinook salmon in other Pacific Northwest watersheds (Eaton, 2010).

There have been limited studies on the effectiveness of the restored tidal channels in the estuary. In 2007 BC Hydro hired an independent environmental consultant to review the past 5 years of restoration activities funded by the BC Hydro Bridge Coastal Restoration Program to determine the effectiveness of the Squamish estuary-based restoration projects (Living Resources, 2008). The spatial and temporal usage of the restored channels by juvenile salmon was identified as a data gap by the SRWS and DFO. To better understand the usage of the Squamish estuary by juvenile salmonids, and in particular Chinook salmon, a pilot study of Chinook usage of the Squamish Estuary was initiated in 2013. Over three years (2013, 2015, and 2016) trapping and seining was undertaken in various habitat types in the Squamish River estuary. The project was completed by InStream Fisheries Research (IFR) on behalf of the Squamish River Watershed Society (SRWS), with funding from the Pacific Salmon Foundation (PSF).

2.0 METHODS

2.1 Fish Trapping

Juvenile salmon were targeted using a variety of net types. Fyke nets, seine nets and custom made large "Gee" style traps were used to capture fish. Habitats targeted included both constructed tidal channels, the central estuary, and margins of the Squamish River along the Squamish Spit Road (Figure 12).

Picture of the fyke net used to capture Chinook salmon juveniles in the Squamish estuary. (Photo credit IFR).

In 2013, monitoring was limited to constructed tidal channels using only fyke nets (Sites 1, 2 and 3) (Figure 12). In 2015, a mixture of custom built large "Gee" traps and fyke nets were used to sample smaller unnamed tidal channels through out the estuary (Figure 12). In 2016, Gee traps were again used in the tidal channels. Due to limited windows of access, fyke nets or "Gee" traps were set in tidal channels overnight twice per week.

Beach seining was tested in late spring of 2015 to enable sampling of the central estuary (Site 18) and margins of the Squamish River along the Squamish Spit Road (sites

26 & 27) (Figures 12). Seining was completed bi-weekly through out the sampling period in 2016.

Sites surveyed over the three-year study are shown as well as the location of the two constructed tidal channels and the central estuary (Figure 12).

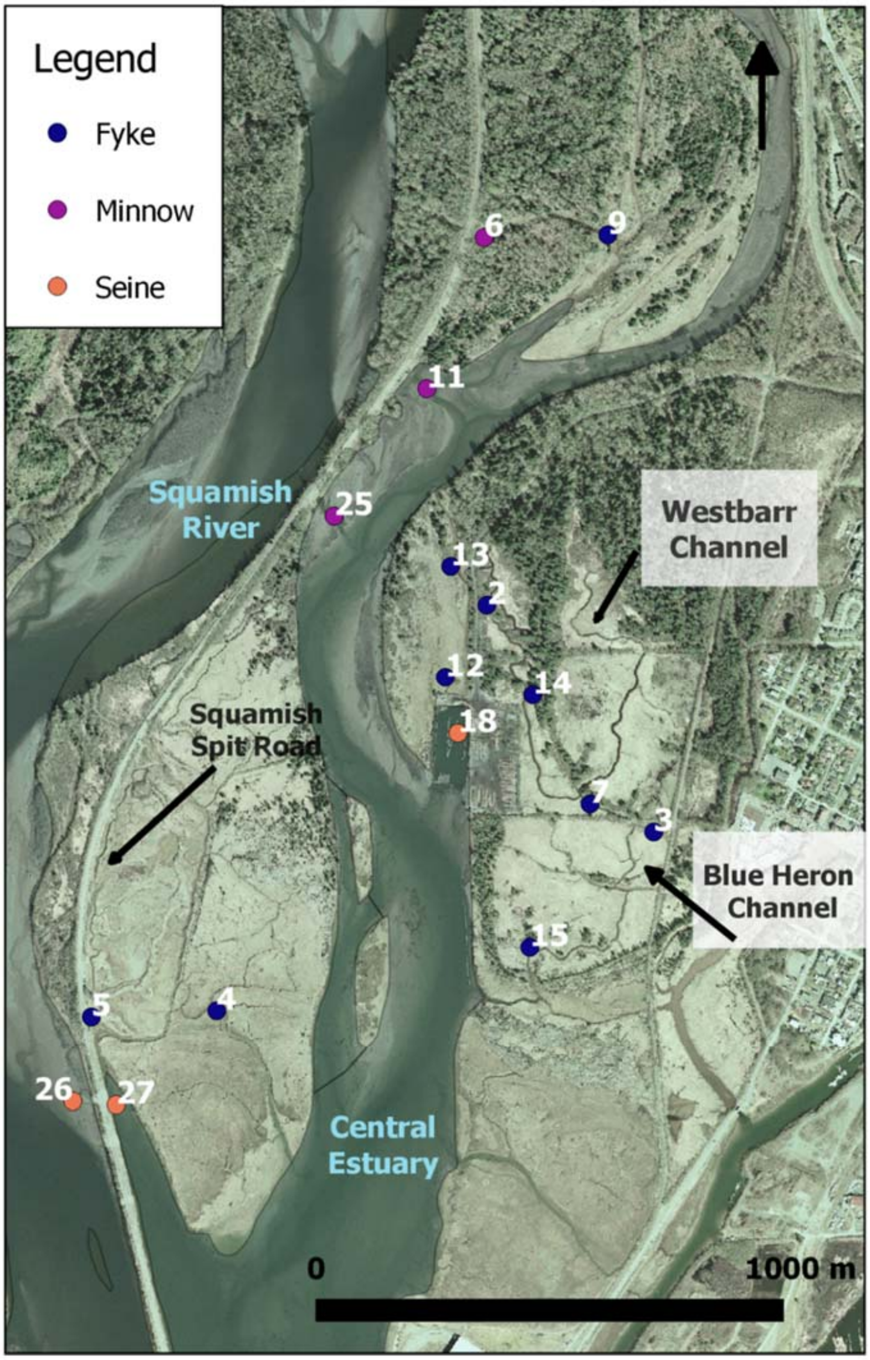


Figure 12. Map of study area in Squamish River estuary

2.2 Biological Sampling

Fork lengths and weights were recorded for all salmonids. For non-salmonids, 20% of total catch up to a maximum of 25 individuals were randomly measured and weighed. Fork length was taken to the nearest millimetre and weight to a tenth of a gram. To ensure accuracy of measurements fish were anesthetised in a water bath of clove oil and ethanol mixed at a ratio of 1:10.

2.2.1 Chinook Salmon DNA Collection

A caudal fin clip was taken from Chinook salmon juveniles for DNA analysis by the Department of Fisheries and Oceans (DFO). Each fin clip was placed in an individual vial and preserved with non-denatured ethyl alcohol. In 2013, fin clips were only taken from fish captured in the estuary. In 2015 and 2016, samples were taken from fish captured in the estuary and at the Cheakamus River rotary screw traps (RST) for comparison of the stocks of origin found in the two habitats. In all years, fin clip collection was completed weekly to ensure fish were sampled over the entire sampling period.

Picture of beach seine site in central estuary. (Photo credit IFR).

2.3 Age Structure Analysis

In 2015 and 2016, scale samples were collected from Chinook salmon juveniles captured in the Squamish River estuary and the Cheakamus River RSTs. Scales were collected from the area above the lateral line and posterior to the dorsal fin. Scales were dried and stored in labelled envelopes. Scales were mounted directly on glass slides and aged under a microscope using methods outlined in Ward and Slaney (1988). Two analysts independently determined age without knowing the size, date and location of capture. Samples were discarded if a consensus between both readers could not be reached.

3.0 RESULTS

3.1 Fishing Effort by Sample Year

A total of 360 sets were completed at 27 sites in the Squamish River estuary between 2013 and 2016. In 2013, sampling was conducted between April and August. In 2015 sampling commenced in February and was terminated in June due to low catches of Chinook salmon. In 2016, sampling began in February and was conducted through September.

Table 3. Dates, Sites and fishing effort across the three survey years of juvenile Chinook salmon monitoring in the Squamish River estuary.

Year	Dates Surveyed	Sites Surveyed	Number of Sets
2013	April to August	1-3	77
2015	February to June	2-15	89
2016	February to September	2-27	194

3.2 Habitat usage by Chinook salmon and other salmonid species

3.2.1 Chinook

Across all three years of survey, a total of 239 Chinook salmon juveniles were captured in the Squamish River estuary. Chinook salmon were found in both the tidal channels and central estuary habitat.

In 2013, Chinook salmon were captured consistently at two of the three sites fished (sites 2 & 3) (Table 4). In 2015, catches of Chinook salmon at sites 2 and 3 dropped from over 30 fish per trap to a total combined catch of 25 Chinook salmon over the 5-month sampling period. At site 3 in 2015, only 2 Chinook salmon were captured over the entire sampling period. Due to low catches in 2015, site 3 was not fished in 2016. In 2016, a new location (site 15) at the southern end of the Blue Heron Channel was selected as a replacement for site 3 (Figure 12).

In 2016, the greatest catches of Chinook salmon occurred at seine sites along the Squamish River training dike (26 & 27), in the central estuary (11 & 18), and in the Blue Heron Channel (15) (Table 4, Figures 13).

Table 4. Catch of Chinook salmon juveniles at individual sites by year in the Squamish River Estuary.

Year	Site	Catch	Min Length (mm)	Max Length (mm)	No. Sets
2013	1	1	52	52	1
2013	2	34	NA	NA	34
2013	3	60	NA	NA	60
2015	2	17	39	105	36
2015	3	2	40	48	6
2015	7	1	90	90	19
2015	12	1	46	46	6
2015	15	4	49	85	8
2016	2	5	42	100	39
2016	11	7	65	88	5
2016	15	18	33	135	31
2016	16	5	47	72	24
2016	18	19	58	104	21
2016	26	39	NA	NA	12
2016	27	18	NA	NA	7

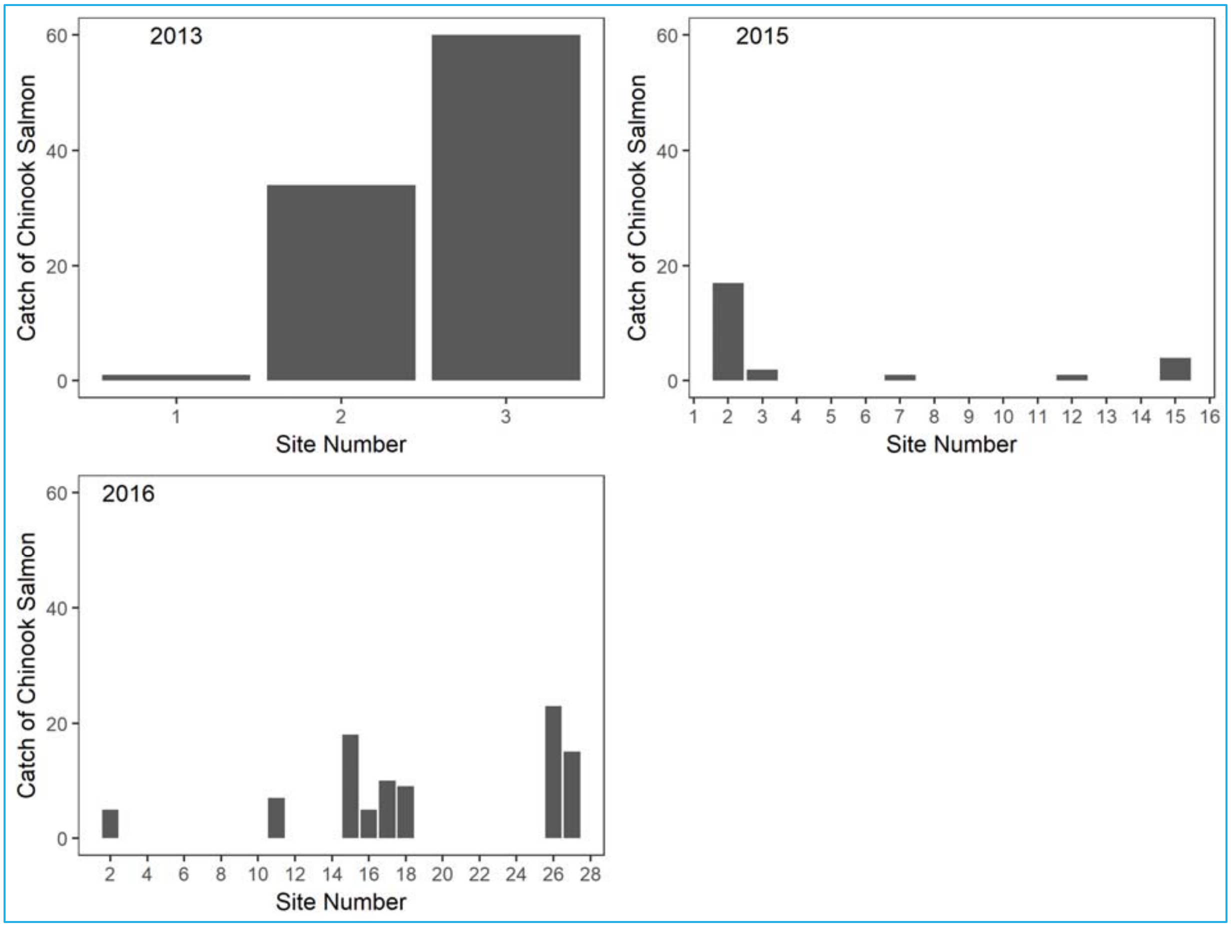


Figure 13. Annual catch of Chinook salmon juveniles in the Squamish River estuary by site number

3.2.2 Coho

Over the 3 years of study, a total of 2,885 coho juveniles were captured in the estuary. Coho were generally found in higher numbers in the tidal channels (sites 2, 3, 7 and 15) than in the central estuary (Table 5, Figure 14). Coho salmon juveniles ranged from 30 mm to 133 mm in fork length. Both YOY (30-70 mm) and yearling (> 70 mm) fish were found using the estuary.

Table 5. Captures of Coho salmon juveniles in the Squamish River Estuary 2013 to 2016.

Year	Site	Catch	Min Length (mm)	Max Length (mm)	Year	Site	Catch	Min Length (mm)	Max Length (mm)
2013	1	24	NA	NA	**2016**	11	1	58	58
2013	2	335	NA	NA	**2016**	12	2	90	91
2013	3	339	30	113	**2016**	15	1273	NA	NA
2015	2	547	NA	NA	**2016**	16	29	32	107
2015	3	33	64	121	**2016**	17	1	50	50
2015	4	1	62	62	**2016**	18	4	79	92

Table 5 continued.

Year	Site	Catch	Min Length (mm)	Max Length (mm)	Year	Site	Catch	Min Length (mm)	Max Length (mm)
2015	7	82	NA	NA	**2016**	23	2	74	103
2015	8	1	NA	NA	**2016**	25	2	95	96
2015	12	10	67	117	**2016**	26	2	31	33
2015	15	69	NA	NA	**2016**	27	18	65	100
2016	2	104	NA	NA	**2016**	29	1	65	65
					2016	30	5	60	90

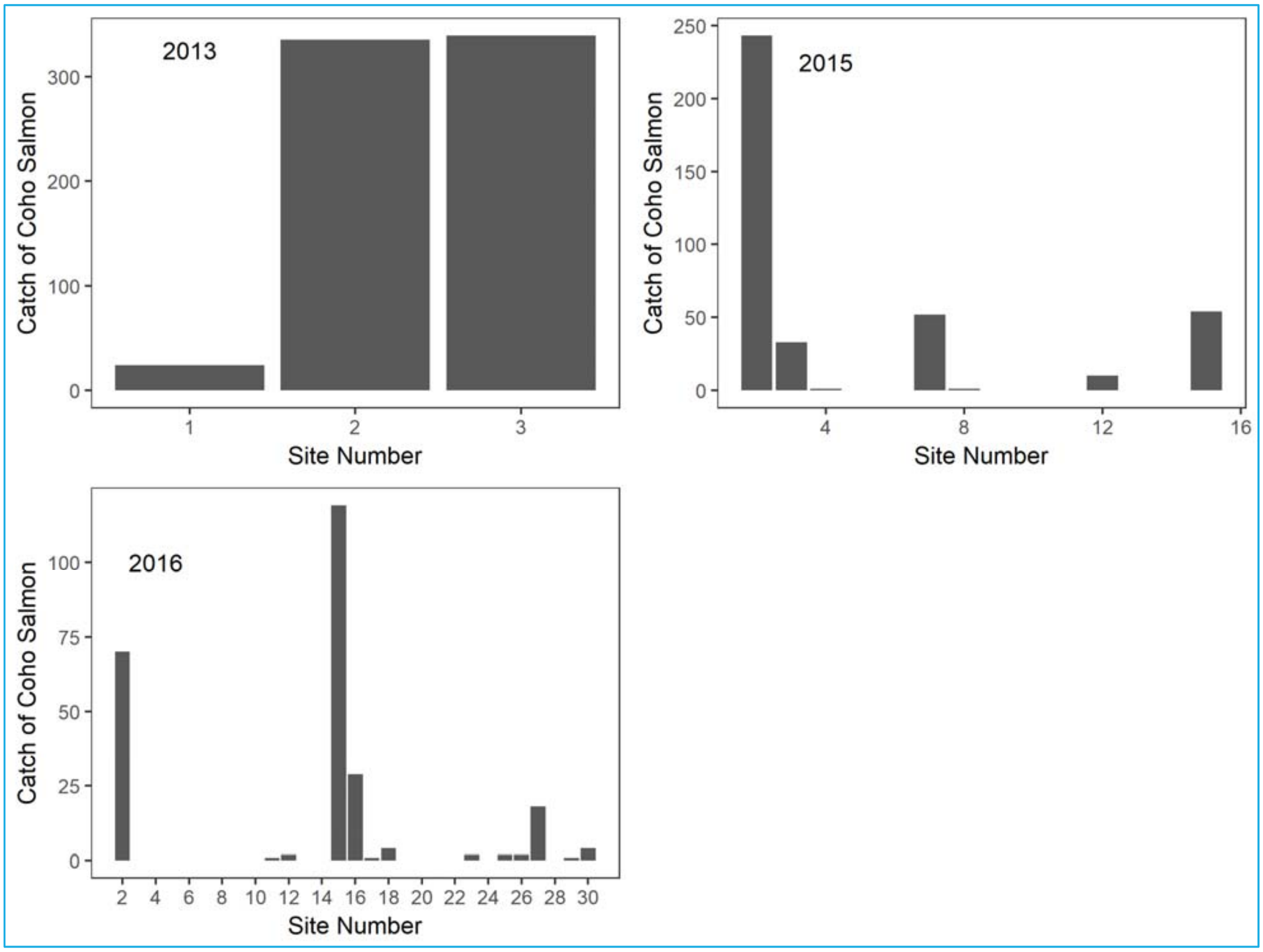


Figure 14. Annual catch of Coho Salmon juveniles in the Squamish River estuary by site number

3.2.3 Pink and Chum Salmon Fry

Chum and pink salmon fry were captured at most sites fished in the estuary. Captures of fry were generally highest in the tidal channels (sites 2, 3, 15 & 16). Moderate catches of fry were also observed at Fry Creek (site 20) and in the central estuary (sites 17-19) (Table 6, Figure 15).

Table 6. Catch of Chum (CMF) and Pink (PKF) salmon fry in the Squamish River estuary 2013 to 2016.

Year	Species	Site	Catch	Min Length (mm)	Max Length (mm)
2013	CMF	2	37	36	64
2013	CMF	3	81	34	57
2013	PKF	2	1	44	44
2013	PKF	3	1	62	62
2015	CMF	2	18	NA	NA
2015	CMF	3	33	NA	NA
2015	CMF	5	1	39	39
2015	CMF	12	1	56	56
2015	CMF	15	2	37	48
2015	PKF	3	1	NA	NA
2016	CMF	2	2	37	42
2016	CMF	12	1	42	42
2016	CMF	15	854	4.6	59
2016	CMF	16	6	33	44
2016	CMF	17	57	NA	NA
2016	CMF	18	7	37	48
2016	CMF	19	22	NA	NA
2016	CMF	20	55	NA	NA
2016	CMF	26	3	35	41
2016	CMF	27	4	40	46
2016	PKF	2	1	33	33
2016	PKF	15	14	NA	NA
2016	PKF	16	17	30	45
2016	PKF	17	2	31	32
2016	PKF	20	8	NA	NA
2016	PKF	21	5	NA	NA

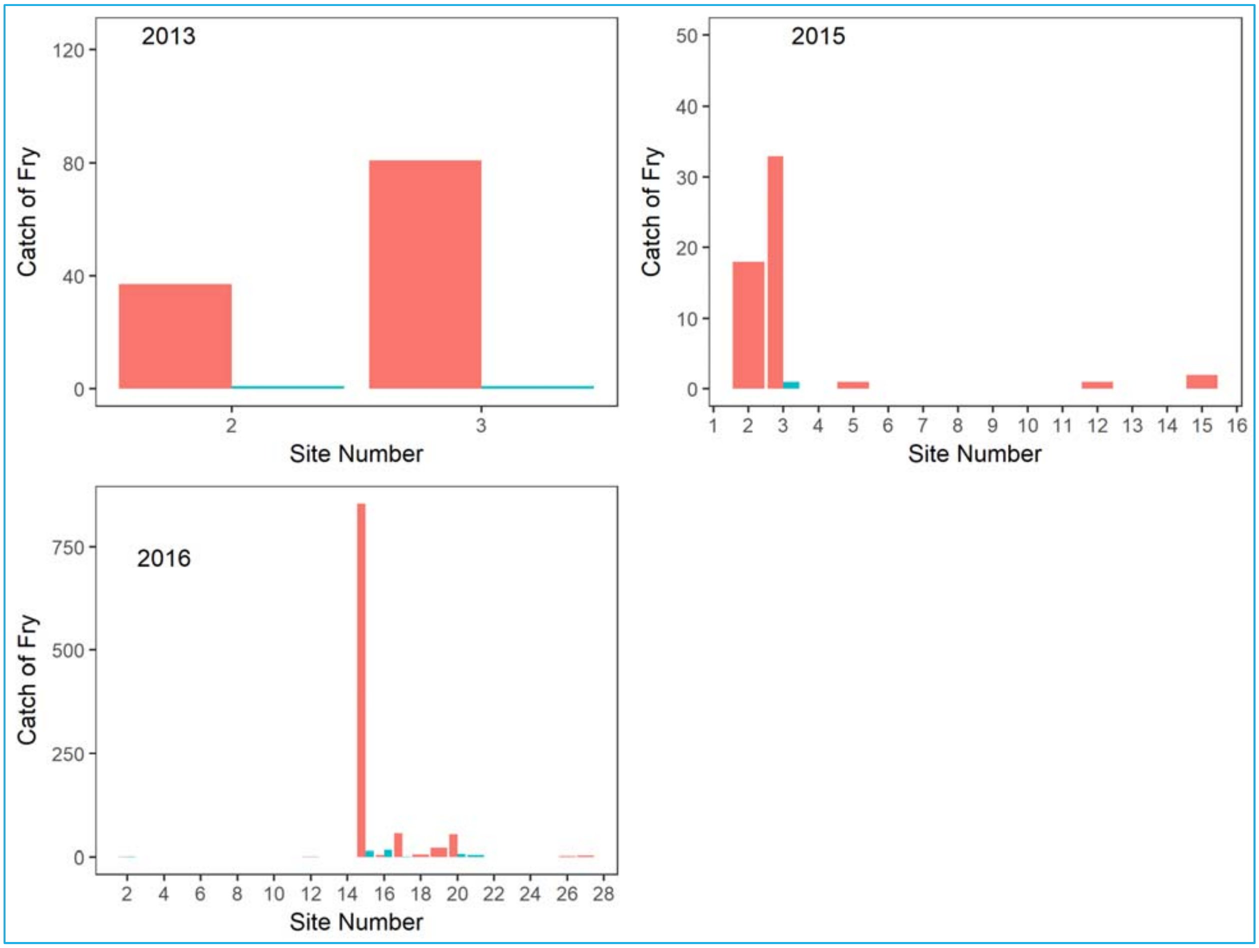


Figure 15. Annual Catch of Pink and Chum salmon fry in the Squamish River estuary by site number (Pink =Chum Fry, Blue = Pink Fry)

3.3 Size and Age Classes of Chinook Salmon Captured in Cheakamus River and Squamish Estuary

Size of Chinook salmon juveniles captured in the Squamish River estuary varied among sample years. In 2013, the majority of fish (88%) captured were between 50 and 80 mm (N=93). In 2015, too few fish were captured to make meaningful inferences (N=25). However, half of the fish captured in 2015 were less than 50 mm in length. In 2016, over half (60%) fish captured were between 50 and 80 mm in length with a greater percentage of fish than 50 mm and larger than 80 mm than in 2013 (Table 7, Figure 16).

Multiple age classes of Chinook salmon juveniles use the Squamish River estuary. Fish captured in the estuary in 2016 ranged from 0 to 2 years of age. Age analysis of scales collected in the estuary (N=13) and Cheakamus River (N=100), in 2016, indicate significant size overlap between age classes of juveniles in the Squamish River watershed (Table 7, Figure 17). Age 0 fish (young of the year) ranged from 30 to 100 mm in length. Age 1 fish ranged from 60 to 120 mm and age 2 fish ranged from 90 to 118 mm.

Table 7. Relative frequency of Chinook salmon captured in the Squamish River Estuary.

Size Class	2013 (N=93)	2015 (N=25)	2016 (N=88)
>50 mm	3%	48%	20%
50-80 mm	88%	28%	60%
>80 mm	9%	24%	19%

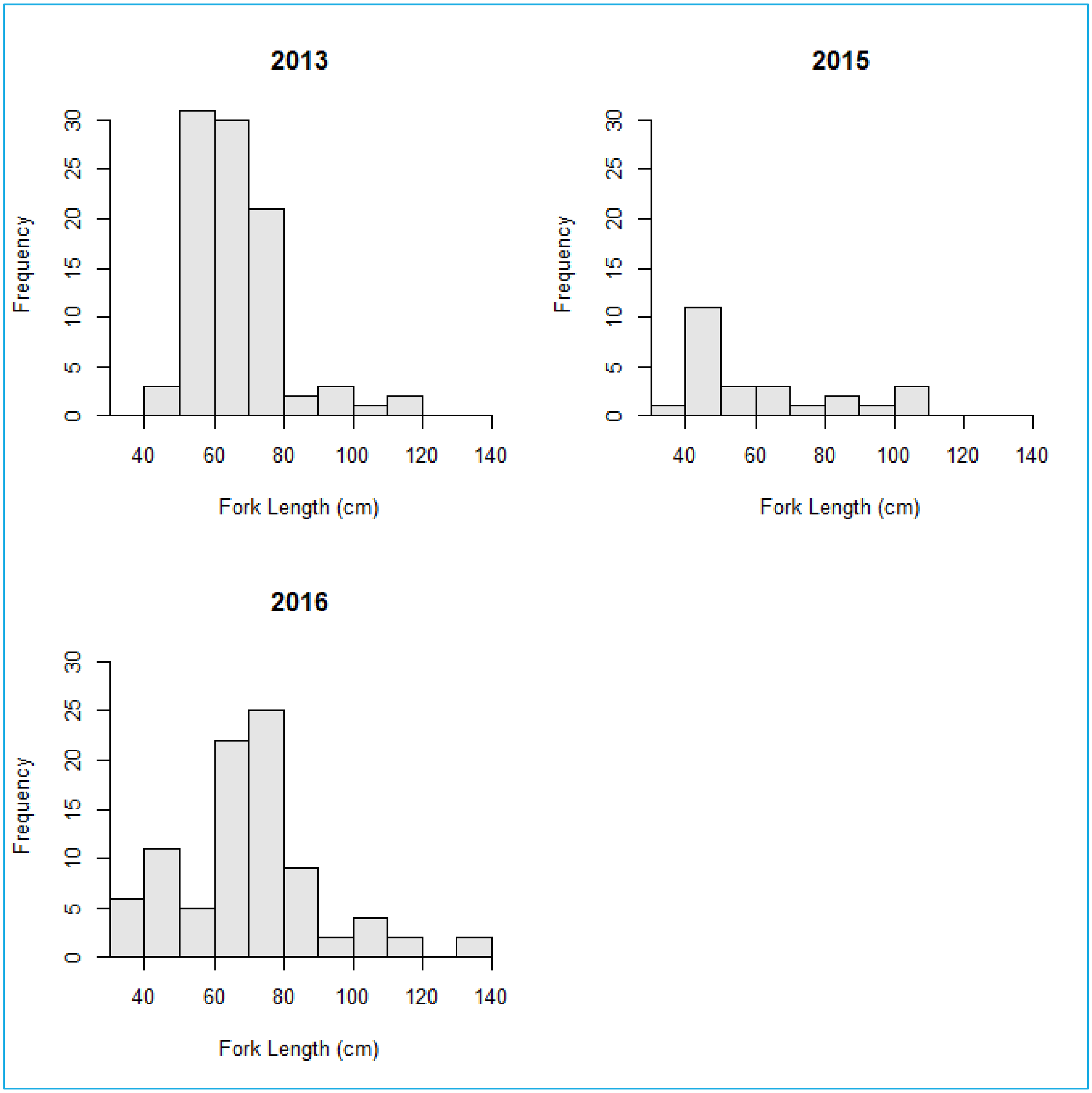


Figure 16. Frequency distribution of Chinook salmon fork lengths (mm) from fish captured in the Squamish River estuary 2013, 2015 and 2016

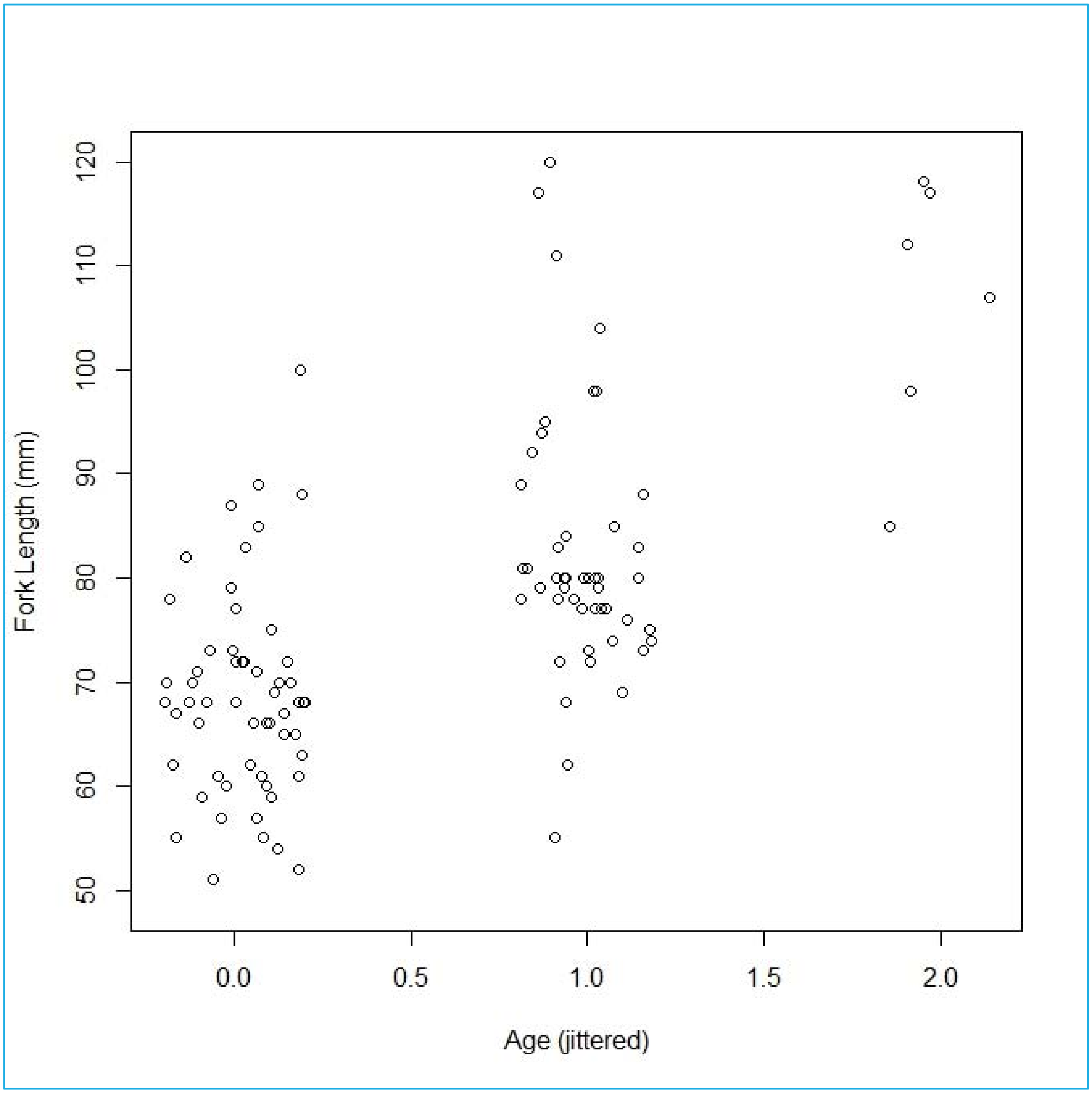


Figure 17. Age-Length plots of Chinook salmon captured in the Cheakamus River and Squamish River estuary in 2016

3.4 Juvenile Chinook Salmon Stock of Origin

In 2013 and 2015, DFO stock identification analysis was completed on juvenile Chinook salmon fin samples collected in the Squamish River watershed. In both years, juvenile fish from other Georgia basin Chinook salmon populations were identified in the Squamish River estuary.

In 2013, a total of 43 DNA samples were collected from fin clips taken in the estuary. Of these samples, 90% of juveniles were from ECVI (Big Qualicum, Little Qualicum and

Puntledge River) and >10% were determined to be from Cheakamus River lineage (Table 7).

In 2015, samples were collected from juveniles in both the Cheakamus River and Squamish River estuary. A total of 63 samples were collected in the Cheakamus River in 2015. Of the Cheakamus River samples, 72% were of Cheakamus River lineage and 28% were of Big Qualicum lineage. Of the 19 samples collected in the estuary, 85% were of Cheakamus lineage and 15% were of Big Qualicum lineage.

Length-Frequency distributions of fork lengths from fish sampled in the estuary for stock identification were created. However, too few samples from Cheakamus River lineage were collected in the estuary in 2013 to compare size to the ECVI stocks (Figure 18). In 2015, too few Big Qualicum lineage fish were collected in the estuary to allow comparison in fish size between stocks (Figure 19).

Samples collected in the Cheakamus River traps, in 2015, indicate a difference in juvenile Chinook salmon size at migration between ECVI and Cheakamus River lineages. In 2015, the majority (65%) of Big Qualicum fish captured in the RSTs were between 35 and 45 mm with few fish over 55 mm (Figure 20). The majority (56%) of Cheakamus River lineage Chinook salmon juveniles captured the same spring were between 45 and 60 mm (Figure 20). A greater percentage of Cheakamus River fish (38%) were over 60 mm than fish from Big Qualicum (18%) (Figure 20).

Table 8. Results of PCR analysis of juvenile Chinook salmon fin clips taken in either the Squamish River estuary or Cheakamus River in 2013 and 2015.

	2013	2015	
Stock	**Squamish Estuary**	**Cheakamus River**	**Squamish Estuary**
Big Qualicum	10	17	3
Capilano	2		
Cheakamus Summer	4	45	16
Chilliwack Fall	1		
Hirsch	1		
Little Qualicum	8		
Puntledge Fall	15		
Squamish	1		
Total Samples	42	62	19

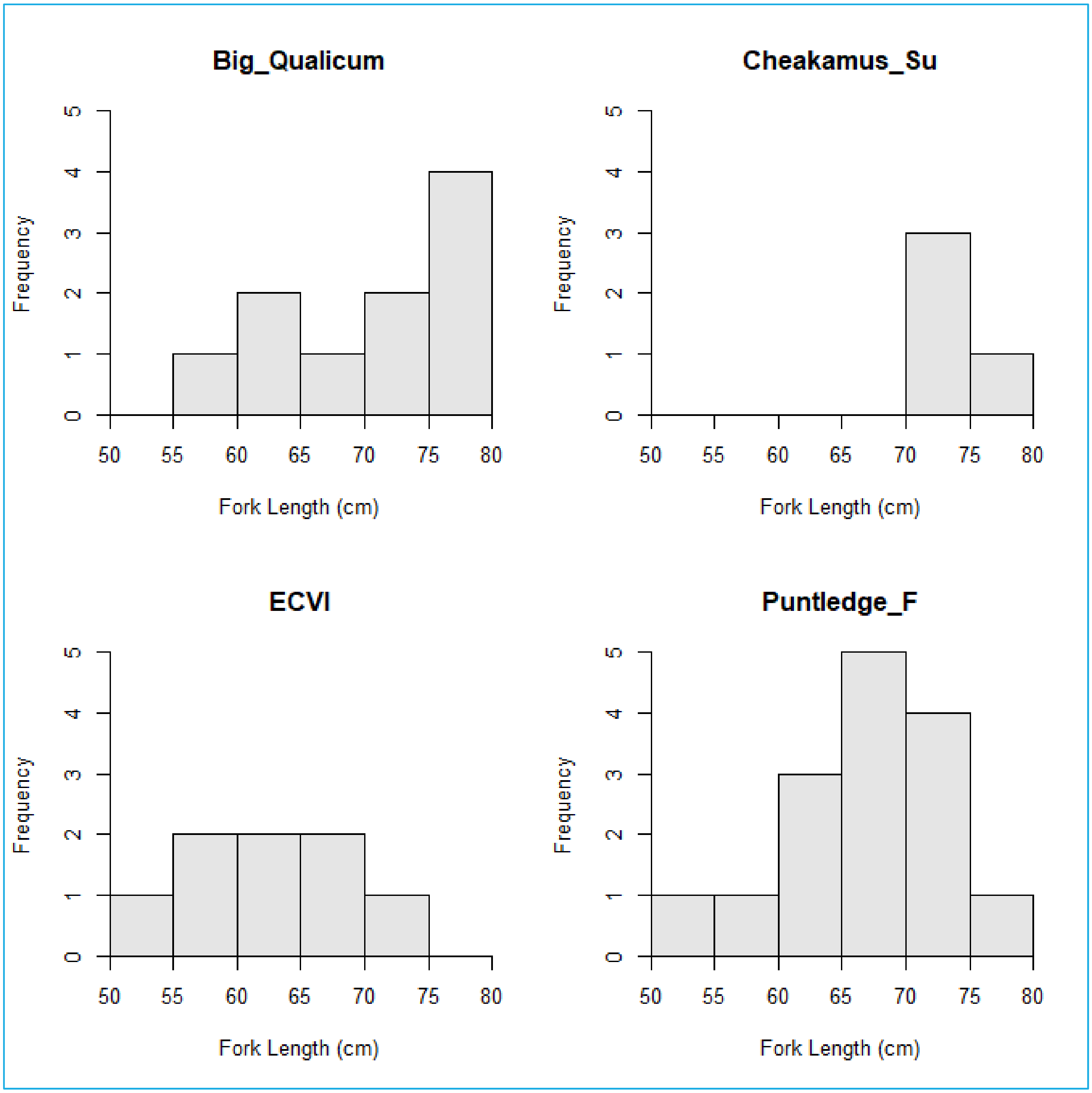


Figure 18. Length- frequency plot of juvenile Chinook salmon from various genetic lineages captured in the Squamish River estuary in spring/summer 2013

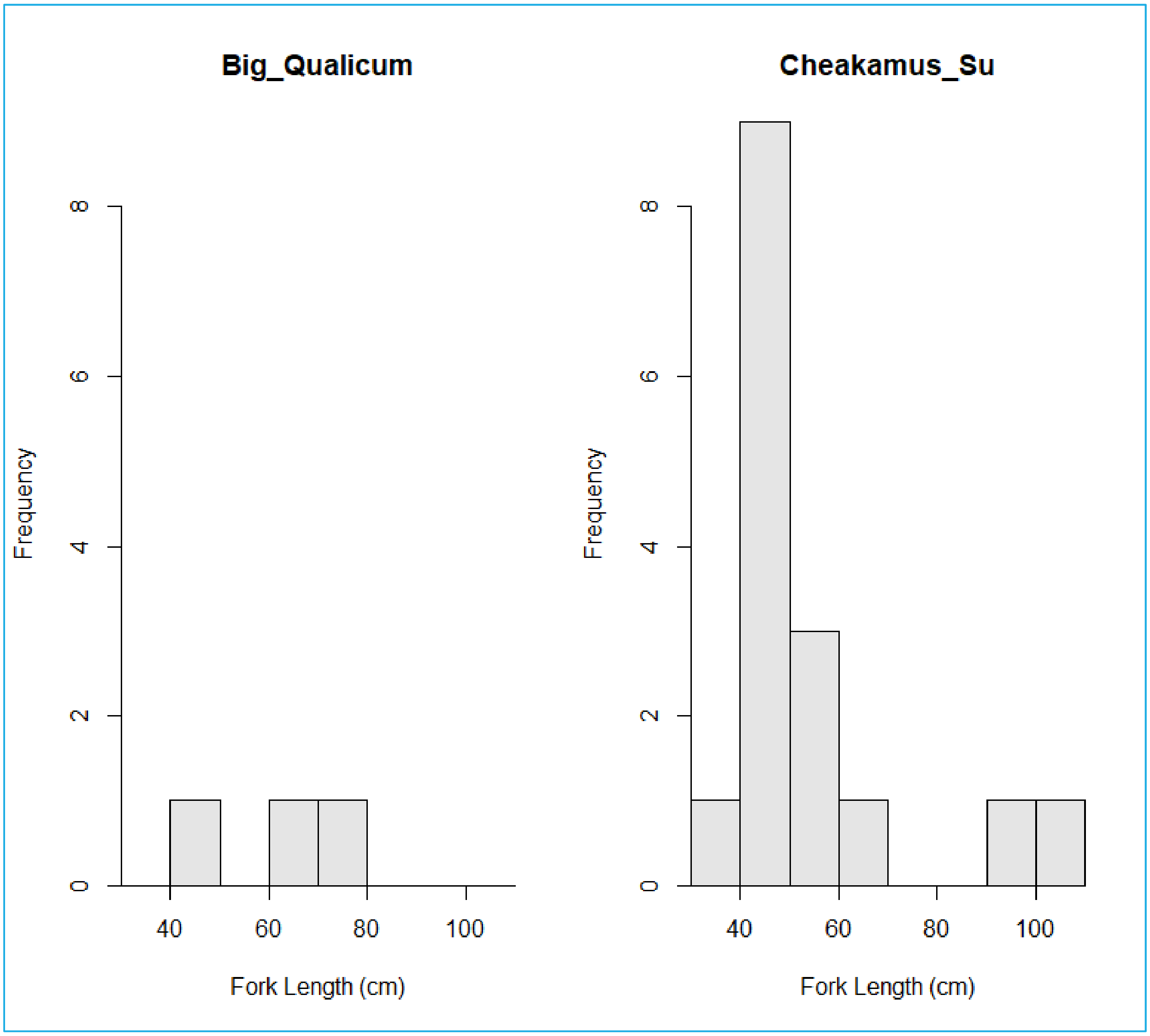


Figure 19. Length- frequency plot of juvenile Chinook salmon from various genetic lineages captured in the Squamish River estuary in spring/summer 2015

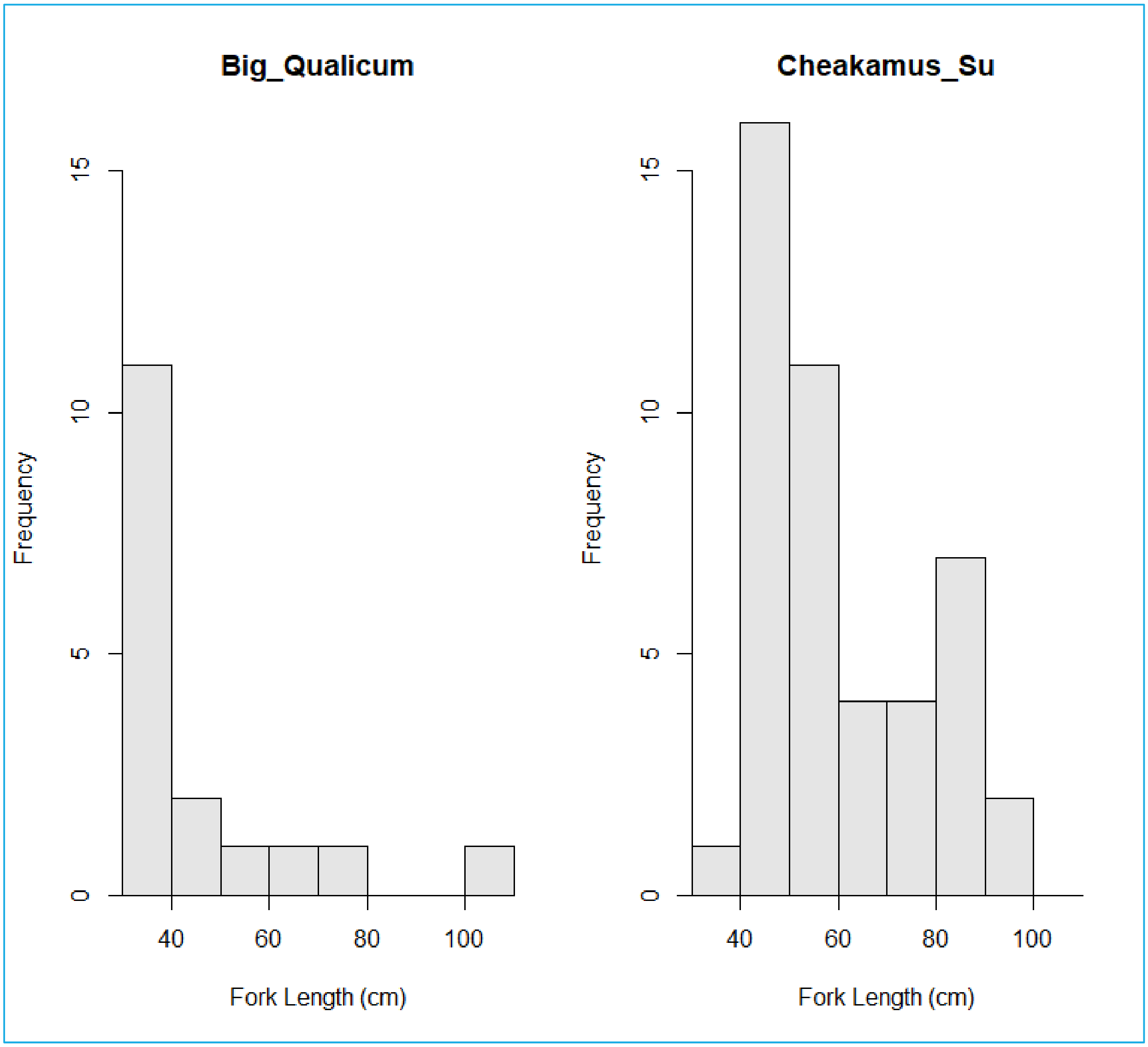


Figure 20. Length- frequency plot of juvenile Chinook salmon from various genetic lineages captured in the Cheakamus River in spring 2015

3.5 Non-Salmonids

Eight species of fish outside of the family Salmonidae were captured during this study: Threespine stickle back (*Gasterosteus aculeatus*), Prickly sculpin (*Cottus asper*), Staghorn sculpin (*Leptocottus armatus*), shiner perch (*Cymatogaster aggregata*), starry flounder (*Platichthys stellatus*), and Pacific herring (*Clupea pallasii*). One Bay Pipefish (*Syngnathus leptorhynchus*) was captured in 2016.

4.0 DISCUSSION

4.1 Chinook Salmon Habitat Usage

This study was successful in capturing multiple size and age classes of Chinook salmon juveniles in the Squamish River estuary. Chinook salmon juveniles were captured in both the tidal channels and central estuary. Seining for juveniles was more successful than trapping in the tidal channels. The data collected in this study indicate Chinook salmon are currently using the mud flats of the central estuary habitat in greater number than the tidal channels. Chinook salmon juveniles are present from March to July, with the peak of abundance in May and June.

Although, catches were low (less than 100 fish per year), the spatial and temporal patterns of habitat use in the Squamish River estuary were consistent with finding in other watersheds. Chinook salmon are generally found on tidal flats with sand or mud bottoms in the low tide and intertidal zones. In the Salmon River (Oregon), juvenile Chinook salmon from emergent fry (< 30 mm) to yearling smolts (> 80 mm) use the intertidal zone of the estuary for weeks to months before entering marine environments (Bottom et al., 2005).

In the Fraser River estuary, however, Chinook salmon juveniles use tidal channels extensively (Dave Nanson, pers comm.). Water temperature in the Squamish Estuary tidal channels may influence usage by salmonids. Due to restricted water flow across the Training Dike, many areas of the tidal channels dry up at low tide and the substrate warms from exposure to solar radiation. Water temperatures in the tidal channels reaches up to 19^{o} C in July and August. Lack of access to the northern end of the estuary through the training dyke may also limit the ability of Chinook salmon to locate and move through tidal channels in the estuary.

Catches of Chinook salmon were highest in the central estuary and in the Squamish River along the spit road. The greatest catches of Chinook salmon were observed at the terminus of the Squamish Spit Road (Figure 12, site 26); in the southern end of the Blue Heron Trail (site 15) and the central estuary (site 11). The relatively high abundance of fish in the Squamish River at the southern terminus of the spit indicates many Chinook salmon juveniles are unable to access the estuary through the culverts in the spit road (sites 5, 6 and 25). Unknown numbers of fish are likely by-passing the estuary and moving directly into deep marine environments. Removal of dikes and improving access to estuarine habitat in other Pacific northwest watersheds has resulted in significant gains in juvenile survival as well as increasing dispersal into more varied estuarine habitats (Cornwell et al., 2001; Gray et al., 2002; Bottom et al., 2005).

4.2 Chinook Salmon Stocks Using the Estuary and Hatchery Influences

Stock identification analysis indicates that Big Qualicum River and Cheakamus River lineage fish are spawning and rearing in the watershed. Both stocks, as well as other stocks from ECVI (Puntledge River and Little Qualicum River) were found in the estuary in 2013. There was a significant decrease in the proportion of Big Qualicum lineage fish between the 2013 and 2015 samples. Catches of Chinook salmon juveniles in the estuary in 2015 were low which limits the inference that can be drawn from the stock identification and size analysis. However, DNA samples from the Cheakamus River indicate a similar proportion of Big Qualicum fish rearing in the watershed as in the estuary.

Establishment of a fall spawning ECVI stocks in the Squamish River watershed is thought to have occurred from past brood stock collection practices by the Tenderfoot Hatchery (Jordan Uittenbogaard. pers. comm). Prior to 2014, the hatchery collected adult Chinook salmon from Porteau Cove. Eggs and juveniles from ocean caught adults were incubated and reared in water from the Cheakamus River prior to being released into Howe Sound or tributaries of the Squamish River. The fall of 2013 was the final year fish were captured at Porteau Cove for brood stock collection. After 2013, all adults have been captured in the tributaries of the Squamish River.

In the spring of 2013, a release of 7-gram Chinook smolts was conducted at the Squamish terminals on the 18th of April (DFO unpublished data). These fish were between 80 and 90 mm in length at the time of release. An additional release of 9-gram Chinook salmon juveniles was conducted in Tenderfoot Lake (part of the Cheakamus River). Although the fish were not marked with an adipose clip, none of the fish sampled for stock identification were with in this size range (largest fish sampled in 2013 was 78 mm). Therefore, it is unlikely that hatchery fish were included in the stock identification samples collected in this project.

In 2014, the hatchery brood stock collection program switched to focus on collecting individuals from tributaries of the Squamish River. Juveniles spawned from adults of each tributary are released into the same tributary adults were collected from to protect genetic diversity. The hatchery releases multiple groups of juvenile Chinook salmon. Groups of unmarked, unfed (> 50 mm) and fed (50-70 mm) fry are released into the Ashlu, Cheakamus and Mamquam Rivers between February and April of 2015. The hatchery also holds some juveniles for a year to release them as yearling smolts (80 to >100 mm fish). These larger fish are marked with coded wire tags (CWT) and an adipose clip. None of the fish sampled for stock identification in this project were marked with an adipose clip in 2015 or 2016. Therefore, we can assume none of the larger hatchery fish were included in the samples from 2015 or 2016. However, it is possible some of the smaller unmarked fry were included in the samples in 2015 and 2016.

Stock identification data indicate the Cheakamus River population was more abundant in the Squamish River estuary in 2015 than any other population in the watershed. In 2015, the only two stocks found in the estuary were Cheakamus River and Big Qualicum River. This indicated that either the baseline for genetic identification in the watershed was not sufficient to detect differences among populations in the Squamish River watershed, or very few juveniles from other tributaries were surviving as far as the estuary.

The Squamish Nation conducts and annual survey of Chinook salmon adult spawners in the Squamish River watershed. Between 2006 and 2015, the Cheakamus River adult counts represented an average of 30% of the total count for the whole watershed. It is possible that the population in the Cheakamus River is larger than other tributaries, and juveniles from Cheakamus River lineage are more numerous than juveniles from other tributaries. Chinook salmon are sparse in the estuary overall; therefore, it is possible that these populations are present in the estuary and this study failed to capture them.

4.3 Competition between Hatchery and Wild Chinook Salmon

Releases of unmarked hatchery fish confound the ability to determine if hatchery and wild Chinook salmon are competing in the estuary. In 2015, unmarked fry (0.3 to 3.0 g) were released into Shovelnose Creek, Chuck-Chuck Creek, the upper Squamish River, Cheakamus River, Ashlu River and the Mamquam River. These fish were between 30 and 70 mm which is similar in size to the fish captured in the estuary during this study. It is possible some of the fish captured in 2015 are the smaller fish released by the hatchery.

Work in the Fraser River estuary indicates hatchery reared fish spend half as much time in estuarine habitats than wild reared fish (Levings et al. 1986). The difference in behaviour between hatchery and wild fish may reduce competition for resources in the estuary. Over the course of this study, densities of Chinook salmon juveniles were low in the Squamish River estuary (annual catches of less than 110 fish) and fish are only found in the southern portion of the estuary indicating there are unexploited habitats at present. Further research is needed to determine weather wild fish are competing with hatchery fish in the estuary.

4.4 Estuarine Use by Other Salmonid Species

Although the focus of this study was on Chinook salmon, all other species of salmon in the watershed were captured over the three years. Bull trout, cutthroat trout, rainbow trout, pink salmon, coho salmon and chum salmon were all found using the estuary to various degrees. Coho salmon were found in highest numbers in the tidal channels indicating a partitioning of habitat use between coho and Chinook salmon juveniles.

5.0 SUMMARY

Chinook salmon are sparse throughout the watershed with only a few hundred adults returning each year. Since 2014, estimates of juvenile Chinook salmon abundance in the Cheakamus River has been consistently low. The results of this study indicate Chinook salmon in the Squamish River estuary are extremely sparse. Despite the challenges of monitoring a small population in a large area, such as the Squamish River estuary, this study was successful in determining that all juvenile life history types use the estuary to some degree during their seaward migration. This study also confirmed the timing of estuary use by Chinook salmon (March through July).

The patterns of habitat use indicate that many Chinook salmon juveniles are likely not entering the estuary prior to entering Howe Sound which may affect survival of juveniles transitioning to salt water environments. Given the sparse population in the watershed, improving access to estuarine habitat should be a priority for future restoration measures in the watershed. Fish may be using the culvert at site 11 (Figure 12), but this area is also part of the central estuary and results from this study are not sufficient to determine how fish are accessing this habitat. A more detailed study of culvert fish passage is ongoing as of 2018.

The stock identification data in this study also indicate the majority of fish in the estuary are migrating out of the Cheakamus River and juvenile Chinook salmon from other tributaries (Ashlu River, Mamquam River, Shovelnose Creek, Chuck-Chuck Creek, and the upper Squamish River) in the watershed are extremely sparse in the estuary. There is a population of ECVI genetic lineage in the watershed and they appear to contribute significantly to overall abundance of juvenile Chinook salmon. Preliminary results of this study indicate there may be variation between juvenile life history strategies between the ECVI and Cheakamus River lineage juveniles in the watershed.

Photo of Chinook caught on Ashlu River, August 2018 (photo courtesy of Jake Mathauser)

VEGETATION AND PLANT COLONIZATION IN THE SQUAMISH ESTUARY

The changes in vegetation, succession of marine flora, and fluctuation of plant ecology over time has been studied extensively since the early 1970s and has included research on environmental disturbance on the distribution of phytoplankton in Howe Sound (Stockner, 1976), seasonal changes of relative abundance and feeding habits of salmonids in the Squamish Estuary (Levy, 1978), ecology of *Fucus distichus* in the Squamish Estuary (Thompson, 1981), as well as the body of work that would become the Squamish Estuary Management Plan Habitat Work Group Final Report (SEMP Habitat Work Group, 1981). In recent years studies completed on behalf of the SRWS, "Effects of Restoration Activities on Plant Communities in the Squamish River Estuary" (Page, 2004), have also provided valuable knowledge.

VASCULAR AND NON-VASCULAR PLANTS

As part of the studies from the early 1970s, twenty-four vascular plants inhabit the tide flats of the estuary were identified, the majority of which are sedges, grasses or rushes. Other than one colony of eelgrass (*Zostera marina*), no submerged vascular aquatics were found in the Mamquam Blind Channel. The east delta was found to be most productive in terms of biomass, followed in turn by the central and then the western deltas (Hoos, 1975).

Since construction in 1972 the Training Dike, marine succession of plant communities has occurred at the central delta front due to reduced freshwater flow and penetration of salt wedge from Howe Sound into the central basin (Levy, 1978).

PHYTOPLANKTON

In conjunction with the Goodman and Vroom study in 1972, the federal government also commissioned a two-year study from 1973 until 1974 on the succession and abundance of phytoplankton in Howe Sound (Stockner, 1976). Stockner determined phytoplankton production in Howe Sound decreased linearly in an up-inlet direction, reaching a minimum at the head of the Sound.

A major factor in phytoplankton production and distribution is light attenuation by the turbid Squamish River. Vernal peaks were observed prior to freshet and dominant species include diatoms. Benthic diatoms originating on the Squamish River delta were common in phytoplankton at the head of Howe Sound. The benthic algal diversity and annual net productivity on the Squamish River delta were greatest east of the Training Dike because of a more stable, higher salinity habitat than on the west delta, which received virtually all the Squamish River runoff.

Species diversity, distribution, and production of benthic algae on the Squamish delta appeared at that time to be greatest in late winter and early spring. During that period increasing light intensity, loss of marsh vegetation, and higher salinity and lower sedimentation rates resulting from low river runoff contributed to optimal conditions for colonization and growth. Benthic algal production on the Central delta was greatest from November to March and least from August to October (Stockner, 1976)

In 1979 a study was published by Timothy Thompson focusing on “Some Aspects on the Taxonomy, Ecology, and Histology of *Phythium pringsheim* Species Associated with *Fucus distichus* in Estuaries and Marine Habitats of British Columbia”. The study found that since 1972 there had been little change in principal vegetation of the central and eastern deltas, despite the deflection of freshwater from these areas by the Training Dike, and the subsequent penetration of a marine “wedge” into the upper marsh.

TIDAL MARSH

Carex lyngbyei and *Eleocharis laustris* were observed to be the principle vascular plants in the Central Estuary. Although the primary vascular flora appeared to be unchanged in the nine years since the dike construction, the advance of *F. distichus* into the upper regions of the delta had been dramatic. In 1972 no *Fucus* occurred in the central delta; the only *Fucus* within the estuary at that time was confined to low logs at the mouth of the estuary, relating to the penetration of the marine waters. By 1976 and 1977 *Fucus* began to appear on the seaward edge of the Training Dike and at the time of the study was widely distributed throughout the central delta. *Fucus* cover appeared to be heaviest on the east side of the Training Dike and at the seaward edge of the central delta. Within the delta, *Fucus* was found not only on log substrata but was frequently directly associated with the sedge community; its holdfasts penetrating into the sediments near rhizomes of *Carex* (Thompson, 1981).

Fucus spp.

SUBTIDAL ZONE & EELGRASS HABITAT

Also, of note is that during the same time, in June 1973, Levings found presence of eelgrass (*Zostera marina*) in the Mamquam delta (SEMP Habitat Work Group 1981). Based on the historical presence of eelgrass the Squamish River Watershed Society, in partnership with the Seagrass Conservation Working Group (SCWG) commenced a program to restored eelgrass throughout the Squamish Estuary. The pilot study was initiated in 2005 with test plots established along the Mamquam Blind Channel, Cattermole Slough, and Central Estuary, as well as at the mouth of Stawamus Creek (Figure 21).

Zostera marina

Figure 21. Eelgrass transplant sites

The difficulties of restoring eelgrass included finding suitable substrate and protected shoreline. Ultimately two key areas were selected. The first site located just upstream of the mouth of Stawamus Creek along the eastern shoreline of the Mamquam Blind Channel at Stawamus on Squamish Nation lands. The second location was along the eastern stretch of the former Nexen lands which has now become the Squamish Oceanfront Development. This pilot study resulted in the planting of over 8,000 eelgrass shoots from 2005 until 2016 with ongoing monitoring to record the condition of the eelgrass growth and health (Wright, 2010).

Volunteers preparing eelgrass shoots for transplant in Mamquam Blind Channel (photo: E. Tobe)

While the eelgrass restoration site located off of the Nexen beach appears to be growing well, the new development plans are to construct a marina on top of this site. Efforts are being made to protect the eelgrass but only time will tell as to the success of this endeavour.

In 2016, as part of the restoration of the West Barr log sort brownfield site, an additional 700 eelgrass shoot were transplanted in the new channel.

A study by Stanhope in the 1980s examined the correlation between amphipods and the various vegetative communities within the estuary (Figure 22). Three habitat types were included in the investigation, all of which are present in the Squamish Estuary: woody debris; a particular type of *Fucus* community; and embankments along the perimeter of *Carex lyngbyei* marshes. In areas where log booms ground at low tide the result was mud flats devoid of macrophytes and with accumulations of bark fragments in depressions along the surface.

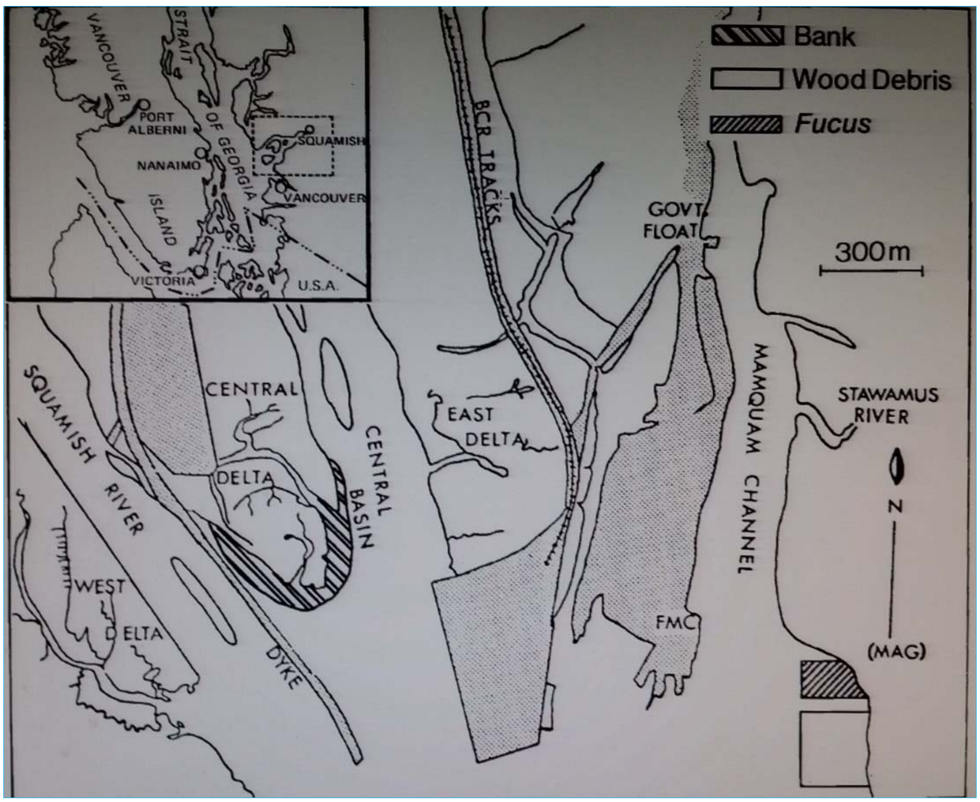


Figure 22. Plant Associations and Primary Productivity (Stanhope, 1989)

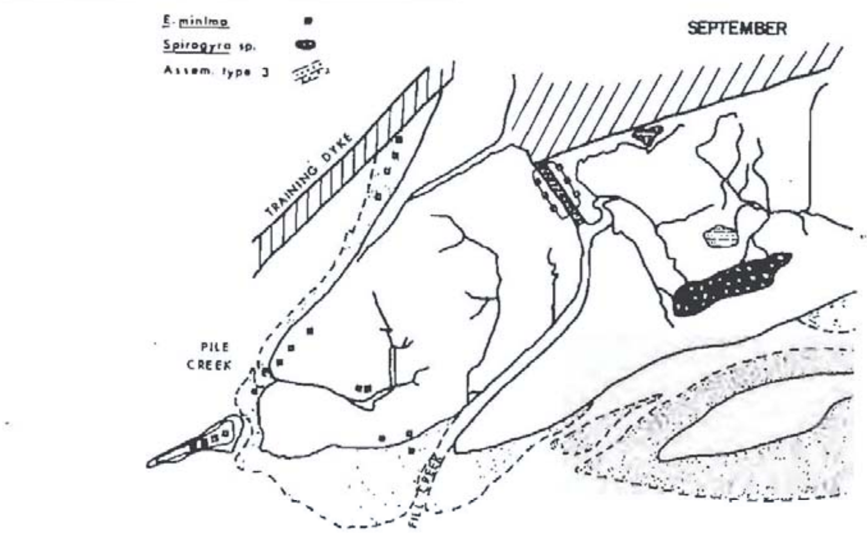
Based on findings by Thompson (1979) comparing the distribution and composition of marsh communities in 1972, the indication was that changes in salinity regime on the delta from the Training Dike had not resulted in changes in marsh vegetation in the central and east deltas.

Vegetation types associated with elevations above high water (4.6 m above low tide) included reed grasses below 0.3 m; deciduous shrub thickets from 0.3 – 0.6 m; Sitka spruce / cottonwood 0.6 – 1.5 m; Sitka spruce / broadleaf maple 1.5 m – 4.6 m (Thompson, 1979)

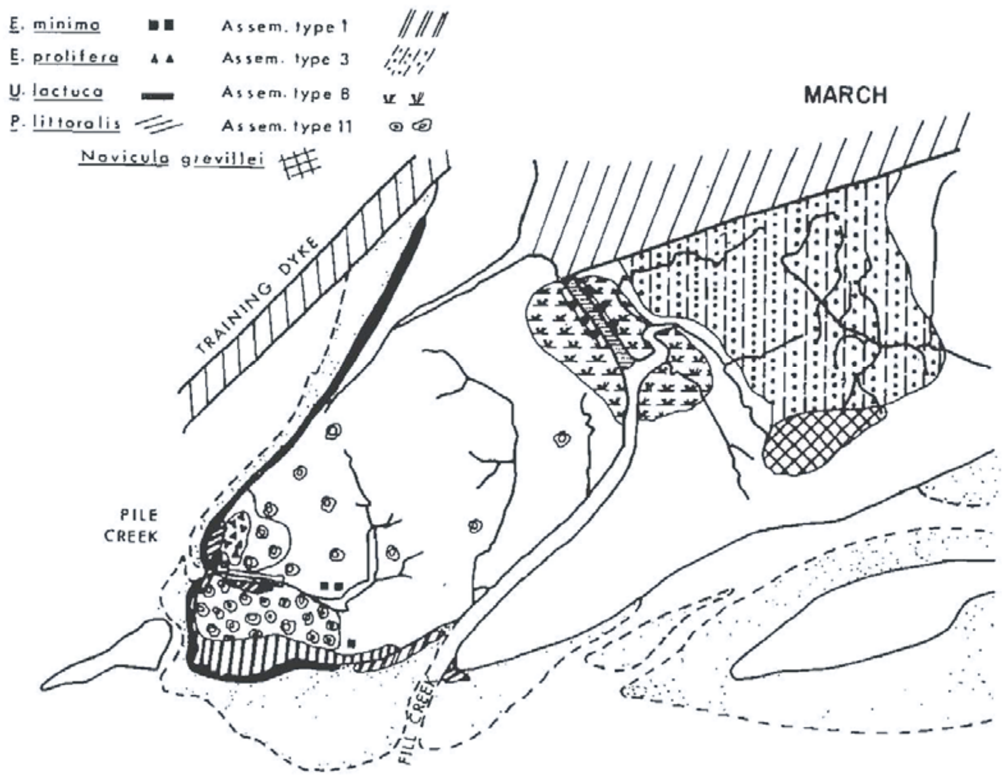
The study also identified within the Central Estuary a total of 96% net primary productivity *Carex sp*. and 4% benthic algae. However, even with these low amounts for primary productivity the contribution by the benthic algae to the function of the estuary remains significant as they:

- are readily available for consumption;
- supply energy for specialized consumers;
- are a likely component in the diet of some invertebrate species;
- are an auxiliary source of detritus when the breakdown of *Carex sp* is lowest; and
- utilize nutrients regenerated from sediments and detritus.

The Squamish River estuary is a detritus-based removal system with most of the energy input and storage attributed to vascular plants of the tidal marsh.



Distribution of benthic algae on the Central delta in September. Representative of summer–fall distribution patterns. (Dotted areas are mud flats exposed at low tide.)



Distribution of benthic algae on the Central delta in March. Representative of winter–spring distribution patterns. (Dotted areas are mud flats exposed at low tide.)

Figure 23. Squamish Estuary Benthic Algae Distribution (Pomeroy, 1976)

Lim & Levings identified 24 species of plants and ten vegetation divisions in the estuary. *Carex lyngbyei* dominates.

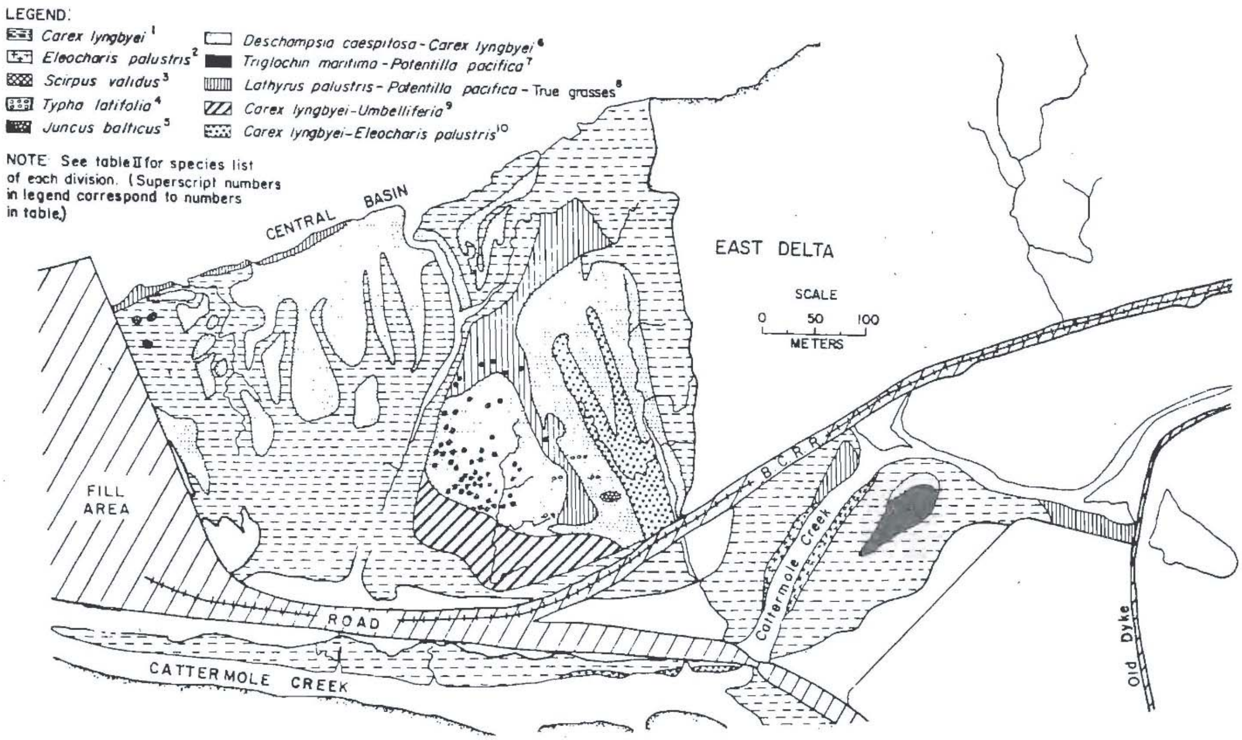


Figure 24. Distribution of vegetation on the East Delta (Pomeroy, 1976) (Table 9)

Table 9. Distribution of vegetation on the East Delta (Figure 24)

Division	Vegetation	Common Name
1	*Carex lyngbyei*	Lyngbye's sedge
2	*Eleocharis palustris*	Spike rush
3	*Scirpus Validus*	Soft-stem bulrush
4	*Typha latifolia*	Cat-tail
5	*Juncus balticus* *Potentilla pacifica* *Triglochin maritima* *Carex lyngbyei* *Eleocharis palustris* *Trifolium wormskjodii*	Baltic rush Silverweed Arrow grass Lyngbye's sedge Spike rush Clover

Table 9. Continued

Division	Vegetation	Common Name
6	*Deschamsia caespitasa*	Tufted hair grass
	Carex lyngbyei	Lyngbye's sedge
	Potentilla pacifica	Silverweed
	Plantago maritima	Seaside plantain
	Sium suave	Water parsnip
	Triglochin maritima	Arrow grass
	Juncus balticus	Baltic rush
	Eleocharis palustris	Spike rush
	Lathyrus palustris	Marsh pea
7	*Triglochin maritima*	Arrow grass
	Potentilla pacifica	Silverweed
	Carex lyngbyei	Lyngbye's sedge
	Sium suave	Water parsnip
	Deschampsia caespitose	Tufted hair grass
	Plantago maritima	Seaside plantain
8	*Lathyrus palustris*	Marsh pea
	Potentilla pacifica	Silverweed
	Aster eatonii	Eaton's aster
	Trifolium wormskjoldii	Clover
	Hardeum brachyantherum	Meadow barley
	Agropyron repens	Wheat grass
	Festuca rubra	Red fescue
	Deschampsia caespitose	Tufted hair grass
	Phalaris arundinacea	Reed canary grass
	Juncus balticus	Baltic rush
	Plantago maitima	Seaside plantain
	Sium suave	Water parsnip
	Cicuta maculate	Water hemlock
	Sonchus arvensis	Field sow-thistle
	Caltha acerifolia	Marsh marigold
9	*Carex lyngbyei*	Lyngbye's sedge
	Sium suave	Water parsnip
10	*Carex lyngbyei*	Lyngbye's sedge
	Eleocharis palustris	Spike rush
	Triglochin maritima	Arrow grass

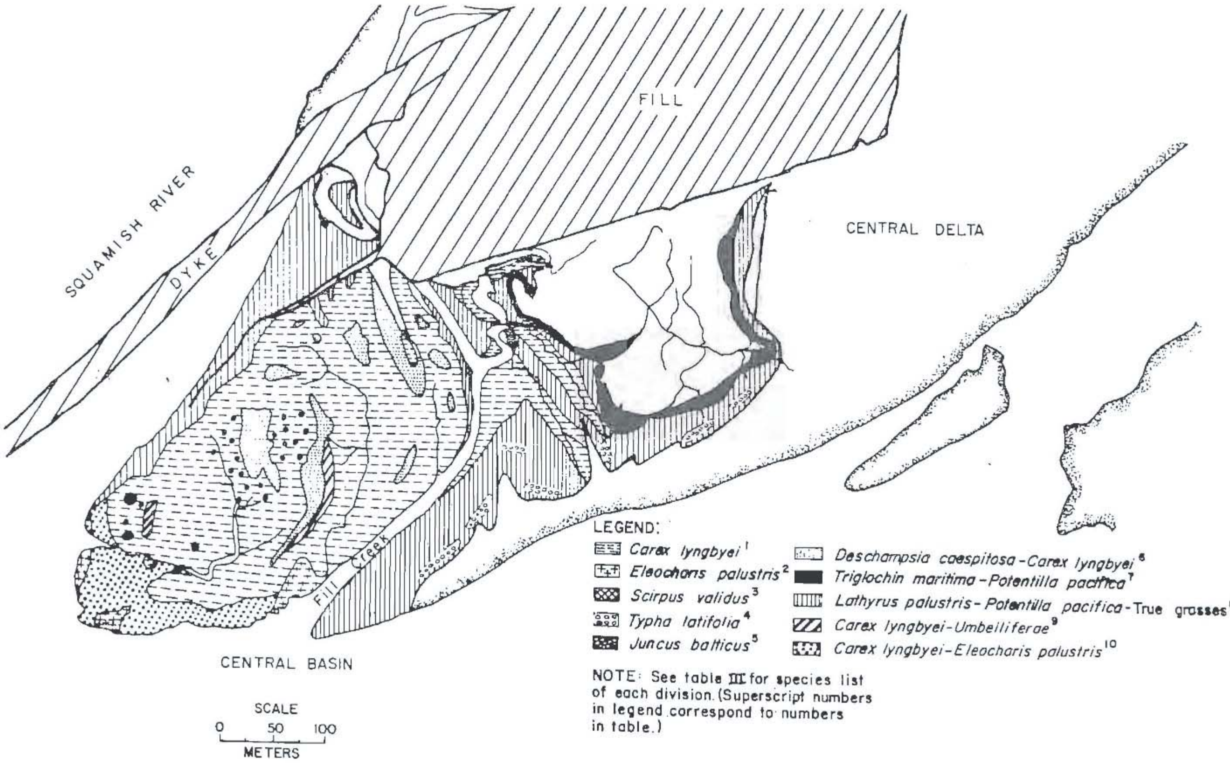


Figure 25. Distribution of vegetation on the Central Delta (Pomeroy, 1976) (Table 10)

Table 10. Distribution of vegetation on the Central Delta (Figure 25).

Division	Vegetation	Common Name
1	*Carex lyngbyei*	Lyngbye's sedge
2	*Eleocharis palustris*	Spike rush
4	*Typha latifolia*	Cat-tail
6	*Deschamsia caespitasa* *Carex lyngbyei* *Potentilla pacifica* *Plantago maritima*	Tufted hair grass Lyngbye's sedge Silverweed Seaside plantain
7	*Triglochin maritima* *Potentilla pacifica* *Carex lyngbyei* *Deschampsia caespitose*	Arrow grass Silverweed Lyngbye's sedge Tufted hair grass

Table 10. Continued

Division	Vegetation	Common Name
8	*Lathyrus palustris*	Marsh pea
	Potentilla pacifica	Silverweed
	Aster eatonii	Eaton's aster
	Hardeum brachyantherum	Meadow barley
	Deschampsia caespitose	Tufted hair grass
	Festuca rubra	Red fescue
	Sidalcea hendersonii	Henderson's checkermallow
	Juncus balticus	Baltic rush
	Sium suave	Water parsnip
	Cicuta maculata	Water hemlock
	Daucus carota	Wild carrot
	Juncus balticus	Baltic rush
	Maianthemum dilatatum	Lily of the valley
	Habernaria delatata	White bog-orchid
	Agrphyron repens	Wheat grass
	Plantago maritima	Seaside plantain
	Triglochin maritima	Arrow grass
	Carex lyngbyei	Lyngbye's sedge
	Elocharis palustris	Spike rush
9	*Carex lyngbyei*	Lyngbye's sedge
	Sium suave	Water parsnip
	Cicuta maculata	Water hemlock
10	*Carex lyngbyei*	Lyngbye's sedge
	Eleocharis palustris	Spike rush


Water parsnip

Lyngbye's sedge


Rice root lily

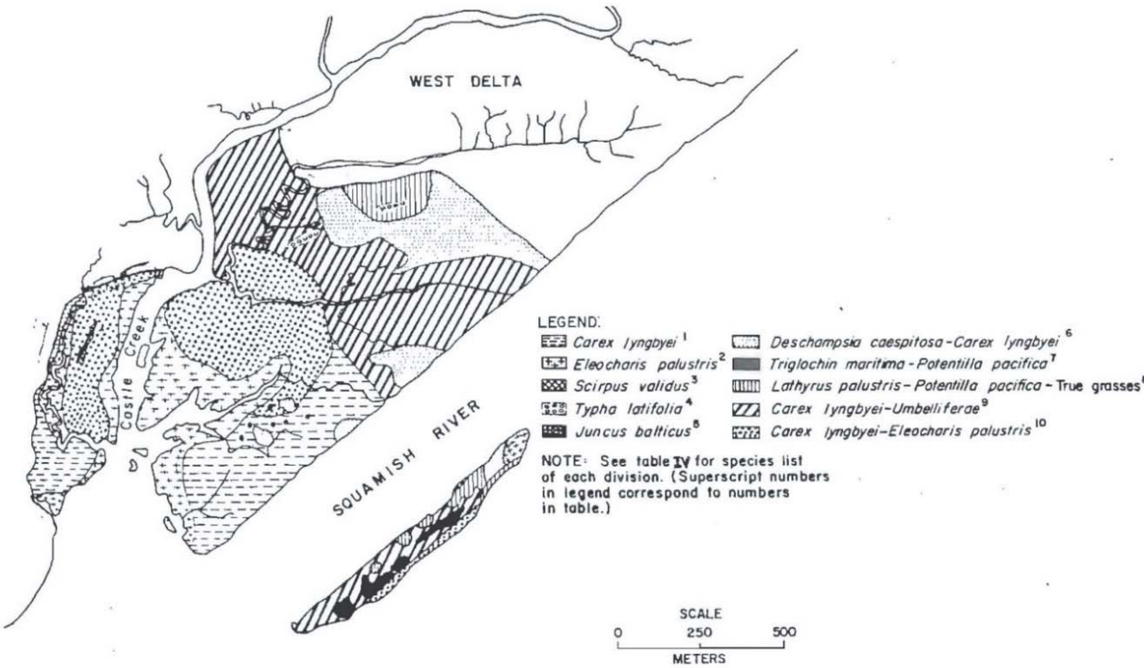


Figure 26. Distribution of Vegetation on West Delta (Pomeroy, 1976) (Table 11)

Table 11. Distribution of vegetation on the West Delta (Figure 26).

Division	Vegetation	Common Name
1	*Carex lyngbyei*	Lyngbye's sedge
2	*Eleocharis palustris*	Spike rush
3	*Scirpus validus*	Soft-stemmed bulrush
4	*Typha latifolia*	Cat-tail
6	*Juncus balticus* *Potentilla pacifica* *Triglochin maritima* *Carex lyngbyei* *Deschampsi caespitose* *Sium suave* *Daucus carota*	Baltic rush Silverweed Arrow grass Lyngbye's sedge Tufted hair grass Water parsnip Wild carrot
7	*Triglochin maritima* *Potentilla pacifica* *Carex lyngbyei* *Eleocharis palustris* *Juncus balticus*	Arrow grass Silverweed Lyngbye's sedge Spike rush Baltic rush

Table 11. Continued

Division	Vegetation	Common Name
8	*Lathyrus palustris*	Marsh pea
	Potentilla pacifica	Silverweed
	Aster eatonii	Eaton's aster
	Daucus carota	Wild carrot
	Trifolium wormskjoldii	Clover
	Sidalcea hendersonii	Henderson's checker mallow
	Maianthemum dilatatum	Lily of the valley
	Hardeum brachyantherum	Meadow barley
	Juncus balticus	Baltic rush
	Plantago maitima	Seaside plantain
	Sium suave	Water parsnip
	Cicuta maculate	Water hemlock
	Carex lyngbyei	Lyngbye's sedge
9	*Carex lyngbyei*	Lyngbye's sedge
	Cicuta maculata	Water hemlock
	Sium suave	Water parsnip
10	*Carex lyngbyei*	Lyngbye's sedge
	Eleocharis palustris	Spike rush
	Triglochin maritima	Arrow grass


Silverweed


Baltic rush


Arrow grass


Cattail

UPLANDS MEADOW

In 2004 a study was commissioned by the SRWS to assess the effects of fish habitat restoration activities on plant communities in a portion of the WMA and to provide management recommendations for plant community and plant species conservation. The focus of the study was to coincide with the tidal channel restoration sites that had recently been constructed in that area (Figure 27) (Page, 2004).

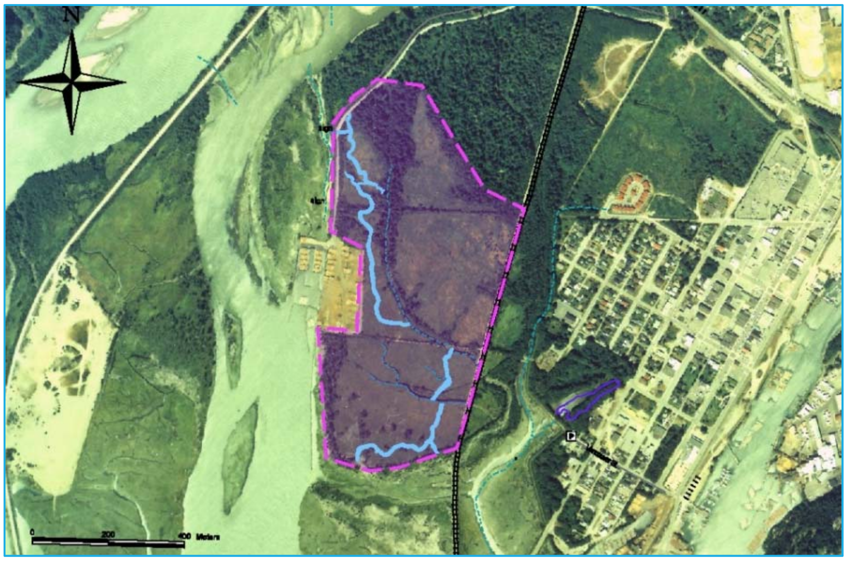


Figure 27. Location of plan study area (Page, 2004)

As part of the study, vegetation was measured in 58 plots in the non-forested portions of the site between July and August 2004. Plots were 5 m by 5 m and plant species richness and abundance (% cover) were estimated visually. Effort was given to select a range of plan communities including disturbed and undisturbed areas. Six non-forested plant community types were identified (Table 12) and were generally aligned on an elevational and successional gradient from lowest and least terrestrial (e.g., *Ruppia maritima* Community) to highest and most terrestrial (*Juncus effuses / Alnus rubra* Community) (Page, 2004).

Bidens amplissima – Blue listed
(Vancouver Island Beggartick)

Sidalcea hendersonii – Blue listed
(Henderson's Checkermallow)

Table 12. Summary characteristics of plant communities in study area

Plant Community	Description and Characteristic Plant Species
1. *Ruppia maritima* (widgeon-grass) Community	*Ruppia maritima* (widgeon-grass) is the dominant plant species within recently excavated tidal channels. It generally monotypic and no other vascular plants occur in this habitat. It is used extensively by waterfowl for grazing.
2. *Carex lyngbyei* (Lyngby's sedge) Community	*Carex lyngbyei* (Lyngby's sedge) is the dominant sedge in estuaries through the north Pacific Coast. It forms monotypic stands at lower elevations and is major component of higher elevation wet meadows. It was more prevalent in the southern portion of the study area and on banks of new channels. Other species: Chenopodium rubrum, *Deschampsia cespitosa, Hierochloe hirta, Potentilla anserina, Hordeum brachyantherum, Triglochin maritimum*.
3. *Lathyrus palustris – Potentilla anserina* (marsh peavine – Pacific silverweed) Community	This community occurs throughout the study area but appears to be at slightly lower elevations than other wet meadow communities. *Potentilla anserina* (Pacific silverweed) and *Lathyrus palustris* (marsh pea) are indicative of seasonal flooding. Species richness is generally low with the nominal species forming dense cover on most sites. *Hordeum brachyantherum* and *Galium trifidum* were also encountered in some plots.
4. *Agrostis stolonifera – Rumex crispus* (creeping bentgrass – curled dock) Community	*Agrostis stolonifera* (creeping bentgrass) is common throughout the study area but forms is most prevalent in wetter areas on the eastern side near the BC Rail line. In combination with *Rumex crispus* (curled dock) and *Typha latifolia* (cattail), it is considered a distinct wetland plant community. It tends to be patchy with some areas dominated by creeping bentgrass and others with higher diversity. Other species include *Bidens amplissima* and *Lathyrus palustris.*
5. *Sonchus arvensis* – Aster subspicatus (perennial sow-thistle – Douglas' aster) Community	This community is the most species rich of the communities of the study area and includes a variety of showy wildflowers. It occurs in seasonally flooded areas but does not undergo daily tidal flooding. It is likely sensitive to hydrologic change. It contains *Sidalcea hendersonii*, *Achillea millefolium, Angelica lucida, Conioselinum pacificum, Elymus repens, Rubus spectabilis*, and *Maianthemum dilatum*. It is similar to a red listed plant community from Vancouver Island.
6. *Juncus effusus / Alnus rubra* (common rush / red alder) Community	This community occurs along the recently created berm crests and near forest margins. It is the driest of the plant communities in the study area and is considered transitional to shrub thicket or young forest. It contains a variety of weedy species, including some common nonnative species. Common species include: Calamagrostis canadensis, *Holcus lanatus, Phleum pretense, Rubus armeniacus, Sambucus racemosa*, and *Agrostis stolonifera*.

BIRD USAGE IN THE SQUAMISH ESTUARY

Numerous studies have been undertaken on wildlife and avian usage within the estuary, document resident and migratory species. In terms of the changes within the estuary as a result of the restoration efforts, the Squamish River Watershed Society commissioned a bird usage study to determine if the restoration works had any negative impacts on the birding populations and to obtain recommendations on actions that could be undertaken to improve habitat and conditions for bird populations. To this effect, Gebauer and Associates studied the areas within the Central Estuary that had been the focus of tidal and marsh restoration efforts and summarized their findings. Table 13 below summarizes the total species found over the three-year period.

Field Survey Methods

The study area was visited approximately every two weeks between 22 April and 24 August 2010 (11 surveys), 12 April and 30 August 2007 (12 surveys), and 21 March and 06 August 2006 (10 surveys). On each survey, the site was traversed by beginning at the railway line in the southeast corner of the study area, walking out on the marsh to the southern end of the restoration works, and then along the east side of the channel to the northern dike. The dike trail was then followed briefly into forest to the west and then back out to the access road along the railway line. The survey took between one and two hours and was generally conducted in the morning. All bird species and individuals were tallied and any birds utilizing the channel areas and adjacent cast materials were noted.

Habitat Description

Site A of the Central Estuary is characterized by areas of open water, large areas of Cattail (*Typha latifolia*) marsh, wet grasslands, and shrub-dominated borders. Rare plant species, including Henderson's Checker-Mallow (*Sidalcea hendersonii*; Blue) and Vancouver Island Beggarticks (*Bidens amplissima*; Blue, Special Concern), have been identified on or adjacent to the site. Common shrub species in riparian areas include Nootka Rose (*Rose nutkana*), hawthorn (*Crataegus* sp.), Pacific Crabapple (*Malus fusca*), Pacific Ninebark (*Physocarpus capitatus*), Sweet Gale (*Myrica gale*) and Salmonberry (*Rubus spectablis*). Tree species, including Sitka Spruce (*Picea sitchensis*) and Red Alder (*Alnus rubra*), are present in areas of higher ground.


Nootka rose


Sweet Gale


Salmonberry in flower

Table 13. Cumulative totals of all bird species observed in the Squamish Estuary in 2010, 2007, and 2006 (Gebauer, 2010)

Common Name	Scientific Name	2010	2007	2006
American Goldfinch	*Carduelis tristis*	21	6	3
American Kestrel	*Falco sparverius*		1	
American Pipit	*Anthus rubescens*		60	1
American Robin	*Turdus migratorius*	46	80	77
Bald Eagle	*Haliaeetus leucocephalus*	4	1	
Band-tailed Pigeon	*Patagioenas fasciata*	38	40	8
Barn Swallow	*Hirundo rustica*		1	
Belted Kingfisher	*Ceryle alcyon*	2	1	1
Bewick’s Wren	*Thryomanes bewickii*	3		
Black-capped Chickadee	*Poecile atricapillus*	41	41	38
Black-headed Grosbeak	*Pheucticus melanocephalus*		6	1
Black Swift	*Cypseloides niger*		140	
Black-throated Gray Warbler	*Dendroica nigrescens*	6		1
Brown Creeper	*Certhia americana*	2		
Brown-headed Cowbird	*Molothrus ater*	12	54	17
Canada Goose	*Branta canadensis*	11	35	64
Cackling Goose	*Branta hutchinsii*			1
Cassin’s Vireo	*Vireo cassinii*	1		
Cedar Waxwing	*Bombycilla cedrorum*	45	60	24
Chestnut-backed Chickadee	*Poecile rufescens*	7	11	10
Common Raven	*Corvus corax*	5	5	3
Common Merganser	*Mergus merganser*		2	
Common Yellowthroat	*Geothlypis trichas*	59	53	41
Cooper's Hawk	*Accipiter cooperii*		1	
Dark-eyed Junco	*Junco hyemalis*		45	2
European Starling	*Sturnus vulgaris*		8	4
Downy Woodpecker	*Picoides pubescens*	2		
Evening Grosbeak	*Coccothraustes vespertinus*	4	1	
Glaucous-winged Gull	*Larus glaucescens*	18	31	
Golden-crowned Kinglet	*Regulus satrapa*	15	18	3
Golden-crowned Sparrow	*Zonotrichia atricapilla*		1	15
Great Blue Heron	*Ardea herodias*	6	5	6

Table 13. Continued

Common Name	Scientific Name	2010	2007	2006
Greater Yellowlegs	*Tringa melanoleuca*		1	1
Green-winged Teal	*Anas crecca*	2	7	10
Hairy Woodpecker	*Picoides villosus*		2	
Hooded Merganser	*Lophodytes cucullatus*		1	
Hammond’s Flycatcher	*Empidonax hammondii*	1		
House Finch	*Carpodacus mexicanus*	1	1	9
Least Sandpiper	*Calidris minutilla*		1	
Lincoln’s Sparrow	*Melospiza lincolnii*	3	1	1
MacGillivray's Warbler	*Oporornis tolmiei*		2	
Mallard	*Anas platyrhynchos*	27	71	13
Merlin	*Falco columbarius*		1	2
Mourning Dove	*Zenaida macroura*		3	3
Marsh Wren	*Cistothorus palustris*	10	2	
Mountain Bluebird	*Sialia currucoides*		4	
Northern Flicker	*Colaptes auratus*	2	4	10
Northern Harrier	*Circus cyaneus*	1	1	
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*		1	
Northwestern Crow	*Corvus caurinus*	46	64	52
Olive-sided Flycatcher	*Contopus cooperi*		1	
Orange-crowned Warbler	*Vermivora celata*	3	6	1
Osprey	*Pandion haliaetus*	6	1	2
Pacific Wren	*Troglodytes pacifica*	2	9	4
Peregrine Falcon	*Falco pereginus*	1		
Pileated Woodpecker	*Dryocopus pileatus*	3	3	
Pine Siskin	*Carduelis pinus*	17	20	2
Purple Finch	*Carpodacus purpureus*	14	13	9
Red Crossbill	*Loxia curvirostra*	12		
Red-breasted Sapsucker	*Sphyrapicus rubber*	1	1	1
Red-tailed Hawk	*Buteo jamaicensis*	1		1
Red-winged Blackbird	*Agelaius phoeniceus*	174	109	101
Rock Dove	*Columba livia*		7	11
Ruby-crowned Kinglet	*Regulus calendula*	2	10	8

Table 13. Continued

Common Name	Scientific Name	2010	2007	2006
Rufous Hummingbird	*Selasphorus rufus*	27	38	18
Savannah Sparrow	*Passerculus sandwichensis*	45	31	75
Sharp-shinned Hawk	*Accipiter striatus*		1	
Song Sparrow	*Melospiza melodia*	63	56	55
Spotted Sandpiper	*Actitis macularia*		11	24
Spotted Towhee	*Pipilo maculatus*	31	24	29
Steller's Jay	*Cyanocitta stelleri*	2	1	5
Swainson's Thrush	*Catharus ustulatus*	34	33	25
Townsend's Solitaire	*Myadestes townsendi*	1		
Townsend's Warbler	*Dendroica townsendi*		1	
Tree Swallow	*Tachycineta bicolor*	5	22	2
Varied Thrush	*Ixoreus naevius*		12	2
Turkey Vulture	*Cathartes aura*	8		1
Vaux's Swift	*Chaetura vauxi*	1	126	
Virginia Rail	*Rallus limicola*	1	1	1
Violet-green Swallow	*Tachycineta thalassina*		230	1
Warbling Vireo	*Vireo gilvus*	3	11	3
Western Wood-Pewee	*Contopus sordidulus*		1	
Western Tanager	*Piranga ludoviciana*	3		
White-crowned Sparrow	*Zonotrichia leucophrys*	6	5	28
Willow Flycatcher	*Empidonax traillii*	27	28	24
Wilson's Snipe	*Gallinago delicata*	4		3
Wilson's Warbler	*Wilsonia pusilla*	5	20	3
Wood Duck	*Aix sponsa*	3		
Yellow Warbler	*Dendroica petechia*	22	18	10
Yellow-Rumped Warbler	*Dendroica coronata*	5	17	2

Conclusions

The new channel and surrounding habitats in the Squamish Estuary have increased habitat diversity in the area likely resulting in a higher diversity of breeding bird species. Belted Kingfisher, Great Blue Heron, Spotted Sandpiper and ducks now use the channel areas, whereas they are unlikely to have done so previously. Although some Cattail habitats were disturbed for channel construction, marsh-breeding birds such as Common Yellowthroat and Red-winged Blackbird are still common breeders at the site. The overall effects of the channel restorations works are considered to be favorable for bird species in the region (Gebauer, 2010).


Mountain blue bird


Hooded merganser


Pacific wren


Merlin


Turkey vulture


Great blue heron

APPENDIX 3: GEOLOGY, HYDROLOGY, AND WATER QUALITY

GEOLOGIC HISTORY OF THE SQUAMISH ESTUARY

The Squamish River Basin lies in the Cordillera physiographic region which is predominantly mountainous, with underlying crystalline and folded sedimentary rock (Zrymiak and Durette, 1979). Located in the Coast Mountains of western British Columbia, the Squamish River watershed drains an area over 3,600 km^2. The Squamish River is high energy and composed of braided, structurally confined, and single-channel meandering reaches (Hickin, 2011). Most of the Squamish River is bordered by steep mountain slopes formed during the Late Cretaceous period made primarily of granitic rocks with some gneiss and schist (Hickin, 2011). The Squamish drainage basin is cut into plutonic rocks of complex origin that formed over an extended period of time from the Late Cretaceous and consist largely of quartz diorite, granodiorite, and quartz monzonite. These rocks are associated with older metasediments and with contemporaneous to younger metavolcanics and Pleistocene volcanics (Hickin, 1989).

Sediment enters the Squamish River from mass wasting events such as debris flows and avalanches. These sediments come from moraine veneers located on steep mountain slopes and vesicular volcanic from Mount Cayley and Mount Garibaldi (Hickin, 2011).

The Squamish Estuary is a fjord-type estuary that was formed by glacial activity centuries ago. Fjord estuaries are characterized by steep sides and deep waters with a shallow barrier at the mouth. In Squamish, the fjord reaches a depth of 285 m (Allison et al., 2011). Fjords also are characterized by strong physical and chemical gradients. There is also a strong gradient in terms of sediment distribution where coarse fluvial sands transition to finer sediments toward the ocean (Gibson and Hickins, 1997; Stockner, 1976; Syvitski et al., 1987) (Figure 28).

Fjord-type estuaries are also characterized by progradational deltas built by the dominant seaward movement of fluvially derived sediment (Gibson and Hickins, 1997). The Squamish River is the primary source of sediment for the estuary (Brucker et al., 2007; Hickin, 1989, Pomeroy and Stockner, 1976). Since the last glaciation period, the delta in the Squamish Estuary has been prograding and has infilled approximately 20 km of the fjord (Brucker, 2007).

Historically, the Squamish River flowed into the estuary through multiple channels, but with the construction of the 1972 Training Dike the main stem river is now confined to the western bank.

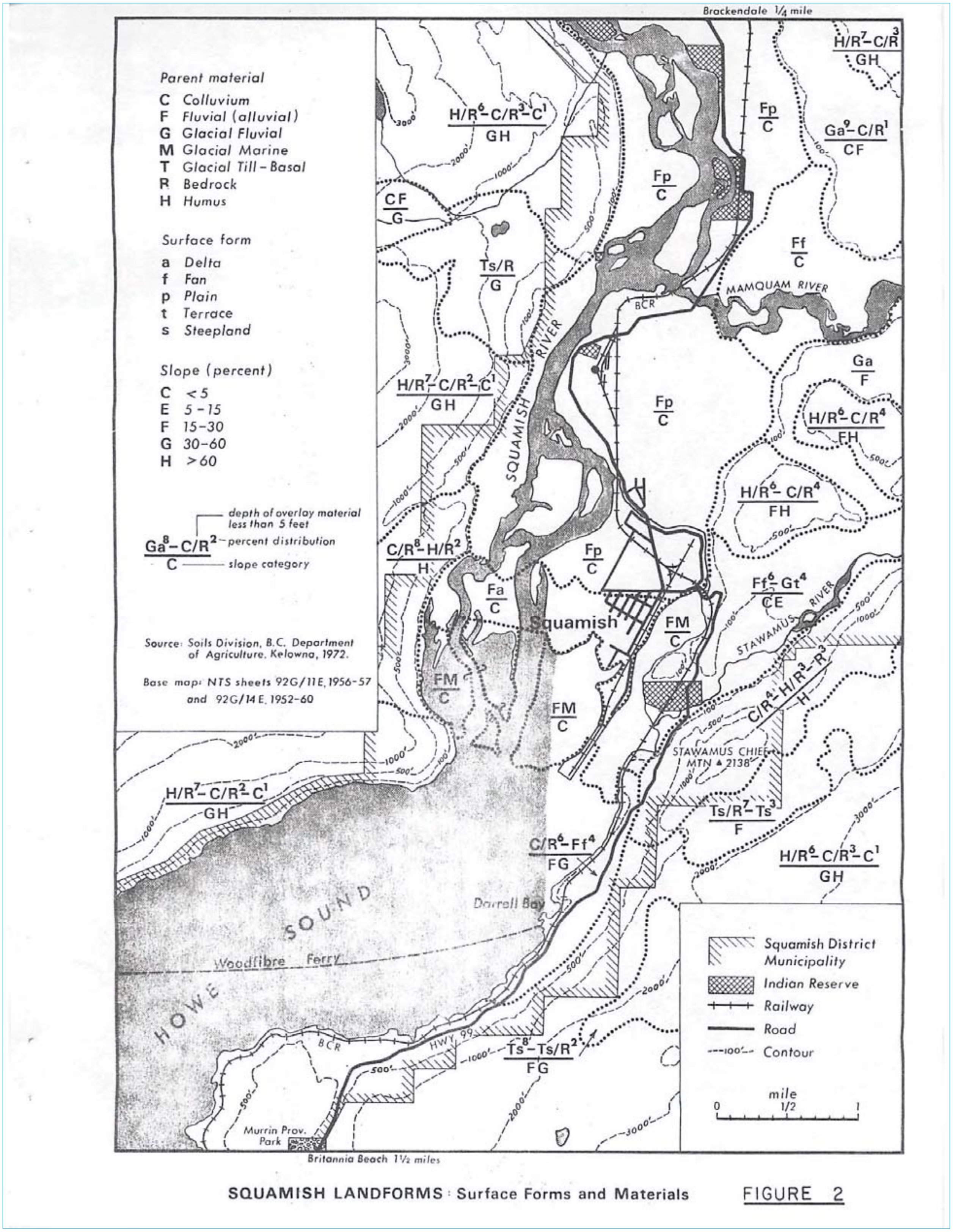


Figure 28. Squamish Landforms (Hickin, 1989)

HYDROLOGY AND SEDIMENT TRANSPORT ALONG THE SQUAMISH RIVER

The Squamish River and the inner portion of Howe Sound represent a classic fjord-estuarine system in that there is a major freshwater input at the head of a long, narrow and deep channel. There is a strong pycnocline (rapid density increase with depth) generated essentially by salinity, between the less dense fresh or brackish surface layer and the underlying high salinity water (Hickin, 1997).

Average annual precipitation in the watershed exceeds 2,000 mm. However, the Squamish River is primarily fed by glacier melt-water and precipitation events. The average annual flow rate of the Squamish River is 250 cms (Stockner, 1976). This is lowest in March at around 90 cms and highest at freshet in July at over 600 cms (Hickin, 1997).

The Squamish Estuary consists of a variety of sedimentary environments from tidal marshes, sand and mudflats, smaller flood channels, and intertidal drainage channels (Ministry of Environment and Parks, 1982; Squamish Estuary Management Committee, 1999). The delta front has coarser sediments compared to the central and eastern part of the estuary, which tends to have finer sediments such as silts and clays (Ministry of Environment and Parks, 1982).

The estuarine circulation is essentially seaward at the surface and landward at depth and can be influenced by such factors as wind and tide. A further feature affecting the circulation in this system is the Squamish Delta, located just south of the Squamish Estuary and the Sill a 70 m deep ridge, located at the end of the channel, between Defense Island and Porteau Cove (Figure 29). The basin, bounded longitudinally by this sill and the head of the Sound, has a maximum depth of about 300 m. The sill acts as a barrier to the free and continuous exchange of water between the basin and corresponding depths to seaward. Levings noted the salt wedge penetration in the river appeared to be dependent largely on river discharge. At low river flows (200 cms) Levings found the salt wedge to reach to the vicinity of the culverts about 1.5 km from the river mouth. During high river flows (500 cms), the wedge did not move past the river mouth (Levy, 1978).

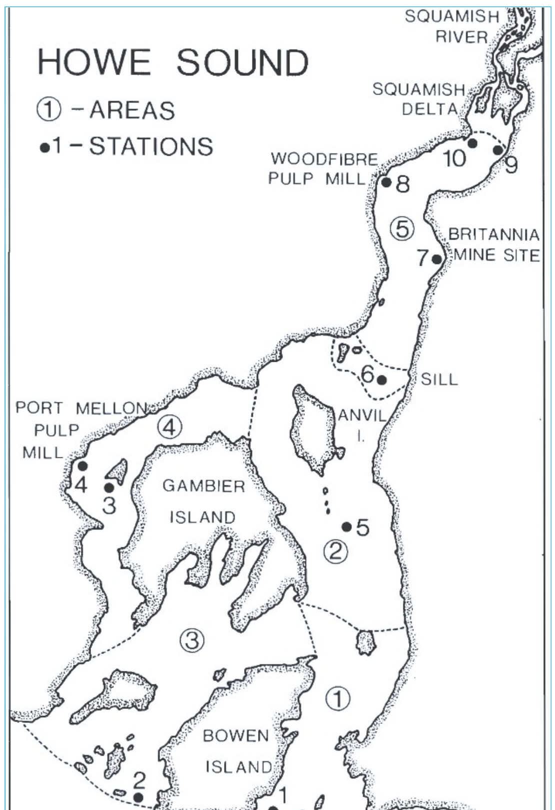


Figure 29. Howe Sound Basin (Stockner, 1976)

The average tidal range in Squamish is 3.2 m, with a maximum of 5 m (Stockner 1976). The Squamish River is very in high energy and tidal influences are greatly decreased at freshet but can be felt upstream to the Mamquam junction at low flow in winter, when tidal amplitudes are at their lowest (Gibson, 1997).

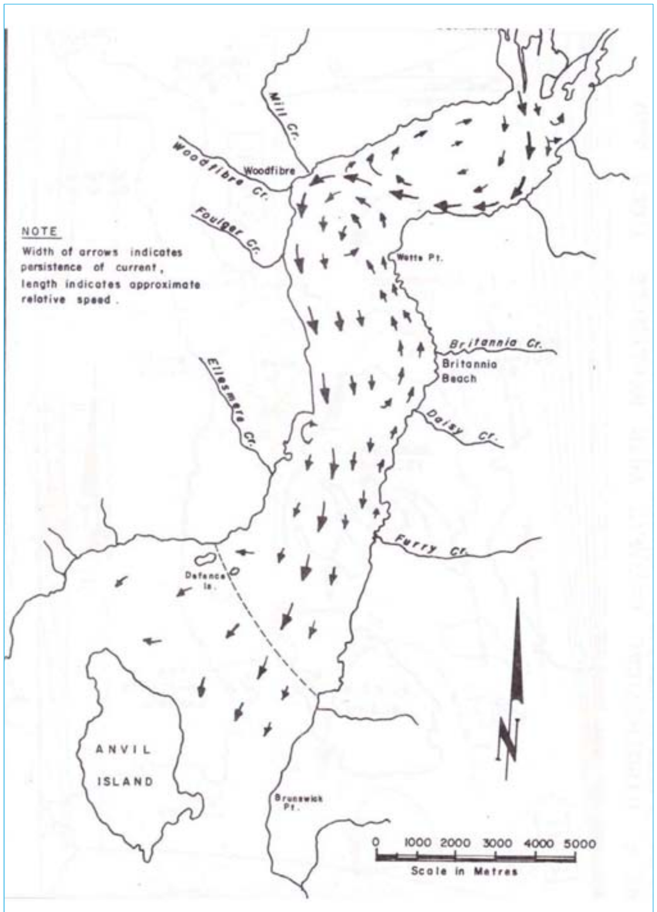


Figure 30. Observed surface current pattern in Upper Howe Sound during a falling tide (Buckley, 1976)

Hickin estimated that on average, 1.29×10^6 m^3 of sediment is deposited in Howe Sound from the Squamish River every year. Sedimentation occurs at a higher rate during freshet because most of sediment (glacial flour) in the Squamish Estuary comes from the river. The sediment accretion rate in the estuary has been observed as 1 m per year for the upper delta (Brucker, 2007). Every year the delta progrades horizontally at a rate of approximately 4 m per year (Gibson, 1997). The movement of sediment combined with in upper Howe Sound is influenced by the tidal flows and seasonal changes (Figure 29) which allow for accretion or erosion depending upon the time of day, year, and river flood event.

In the early 1970s, several studies were undertaken to determine changes in the water and sediment characteristics of the Squamish River and the inner estuary following dredging and construction of the dikes. In 1973, 1974, and 1978, surveys were conducted to monitor the sedimentation process in the Squamish River from the delta to a point about 1 km downstream from the Mamquam River confluence (Zrymiak and Durette, 1979). The results were summarized for the upper (2.27 to 3.42 km from the delta), middle (0.4 – 2.27 km from the delta) and lower (delta to 0.4 km) estuary section of the river. In the upper estuary section, there was a net degradation of the substrate resulting from increased river velocities and erosion due to the river training. However, the upper estuary section was considered to be stable back in 1980 during the study period (SEMP Air and Water Quality Work Group, 1981).

A steady state of aggradation of sediment in the middle estuary gave an increase in mean river bottom elevation and a decrease in average downstream slope. The aggradation along the northwest bank due to erosion is causing the river bend to migrate downstream. This in turn is forcing the river to flow diagonally across the channel and cause some erosion along the dike. The middle estuary section was also observed to be stable during the 1980 study.

In the lower estuary section, there was a net aggradation of sediment with indications that the delta is advancing at a steady state. Sediment deposition was occurring both along the delta face and at the front of the dike. The latter was attributed to the diagonal river flow and dike erosion occurring just upstream in the middle section.

Changes were noted in salinity, temperature, and dissolved oxygen (DO) in association with the construction of the Training Dike. There has been almost complete elimination of the riverine water flow to the east area (also referred to as the Central Basin) resulting in a change from brackish to a more marine condition. Fresh water input had been reduced to flowing through the initial two culverts constructed in 1971 which had, at the time, a maximum flow capacity of 1.5 cms (Bell, 1975).

Observations of sediment transport over a two-year period from 2017 to 2018 (courtesy of J. Buchanan)

A sediment study was undertaken on behalf of the Squamish Terminals in 2016 to examine the transport of sediment from the Squamish River and examine the rate in which the western berth is impacted. The results of the study examined a model that combined sediment transport and hydrodynamics to investigate the sedimentation regime (Tetra Tech 2017). The model was run over a 7-month period from April to August 2016 to cover the freshet period and summer low flow. Other flow events throughout the year were considered negligible. The results of the modelling (Figures 31 and 32) illustrate the cumulative deposition and scour pattern in the early summer and late summer periods. The yellowish-brown colour indicates deposition whereas the blue colour indicates scour measured in metres.

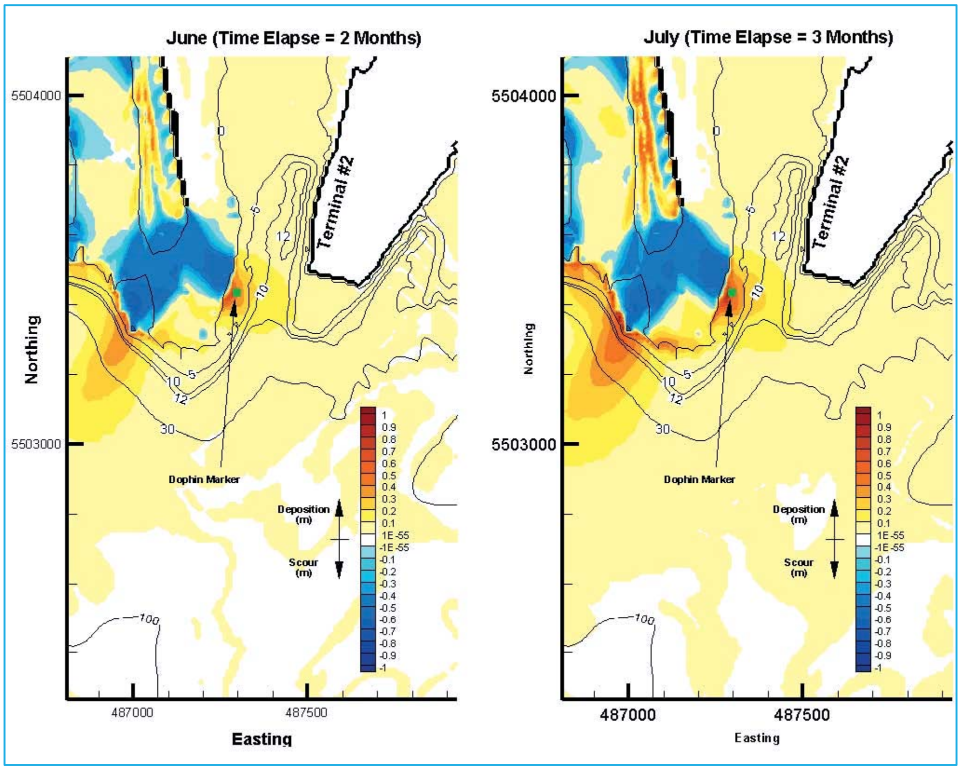


Figure 31. Cumulative sedimentation in the vicinity of Berth 2, June and July 2016 (Tetra Tech, 2017)

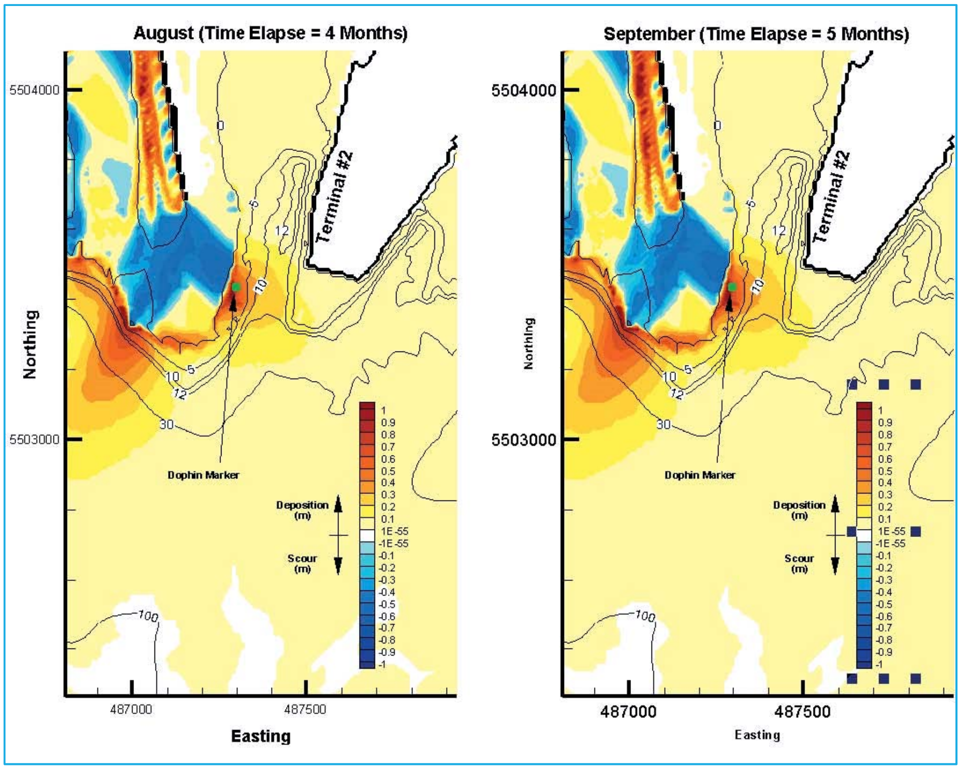


Figure 32. Cumulative sedimentation in the vicinity of Berth 2, August and September 2016 (Tetra Tech, 2017)

From the study, Tetra Tech determined the sedimentation activities occur at a higher rate in the early part of the simulation when the flow is higher during spring / early summer freshet (May and June). In the summer months (July, August, and September) the rate of sedimentation decreases noticeably. The model indicated that active deposition occurs near the edge of the tidal flats downstream of the Spit, in particular at the location of the dolphin marker (as illustrated in the above figures). The model did not take into consideration the underwater landslides which could potentially redistribute large amounts of material from the tidal flats to deeper areas below the Squamish delta (Tetra Tech, 2017).

As part of a 10-month long program which involved surveying of the Squamish delta, from November 2010 to September 2011, Hughes Clarke was able to study the temporal change on the Squamish delta front as the freshet waxed and waned. The results of this study identified 103 discrete mass wasting events, consisting of trains of displacements along one of three active channels (Hughes Clarke, 2012)[5]. Five of these events were triggered by a major (> 20,000 m^3) collapse of the delta lip. Two of these collapses were occurred prior to the spring freshet and were associated with spring low-flow conditions. The trains of successive deposition and erosion associated with the periodic bedforms in

[5] More information on this study and thesis can be found at the website: http://www.omg.unb.ca/Projects/SQ_2011_html/

the channel floor were suspected to be upslope migration. There are no studies to compare these events with prior to the construction of the Training Dike but any changes or modifications along the Dike or the Spit will be closely modelled to add to the study and better understand the natural pro-delta subterranean slides.

INFLUENCE OF TRAINING DIKE

The western portion of the estuary fed by the Squamish River remained mostly undeveloped until 1971 when BC Rail constructed a 5 km Training Dike to install a deep-sea coal port in the estuary. When the Training Dike was constructed, the western arm of the Squamish River was straightened and dredged. The Training Dike confined the flow of the river to the western arm cutting off any water inflow to the eastern part of the estuary resulting in several impacts to the sedimentation regime in the estuary.

The work on the Training Dike was “held in abeyance” until environmental impact studies were completed during 1972. These studies, largely conducted by various regional components of the newly formed federal Department of the Environment, contributed to the report “Effects of Existing and Proposed Industrial Development on the Aquatic Ecosystem of the Squamish Estuary” released in October 1972.” This report, in short, indicated the potential threat of the proposed development on the delta ecosystem, particularly regarding commercial and recreational fisheries (Hoos and Vold, 1975).

The Training Dike has restricted the input of sediment to the western edge of the delta, and historic channel systems are being infilled with overbank sedimentation from the northwest (Brucker et al., 2007). The environment east of the Training Dike has changed to become more saline and siltier (Ministry of Environment and Parks, 1982). After the installation of the Training Dike, the sediment in the west delta became, on average, coarser than that in the central estuary. This was due to the influence of the high energy river flows in the western arm (Ministry of Environment and Parks 1982). Channelizing the river increased river flows and velocity, increased erosion, and increased the sediment load in the river (Levings, 1980; Ministry of Environment and Parks, 1982). Due to increased erosive forces, the Squamish River shoreline receded westward approximately 10 m over 5 years from 1972 to 1977 (Levings, 1980).

With the installation of the Training Dike, sediment aggradation and deposition rates changed. In the west delta, the aggradation rates were 1.0-1.5 cm/year and in the central delta the rate was significantly lower at 0.5 cm/year (Pomeroy, 1976). The remaining deposition in the central delta no longer was derived from the river but instead from tidal action (Levings, 1980). Gibson and Hickin (1994) found that sediment deposits increased on the western side of the dike from 1-6 cm/year before 1972 to 5-7 cm/year after the dike was installed. Kerr Wood Leidel (2015) estimate that as the delta progrades beyond the training dike, sedimentation will be more dispersed, and the rate of delta advancement will decline.

Furthermore, several studies on the Training Dike indicated the salinity in the eastern portion of the Squamish River was much higher than that in the western arm. In the western arm, salinity varied considerably with depth and there was a noted change of up to 25% depending on the river flow and tidal amplitude. However, within the central basin of the estuary, the salinity varied less than 6% (Pomeroy, 1976). Historically, the entire estuary probably experienced a salinity regime somewhat resembling what now exists west of the dike; i.e. brackish water habitat with strong vertical salinity gradients over the entire area (Pomeroy, 1976).

The two culverts installed in 1971 were found to be ineffective at producing a significant freshwater flow into the central portion of the estuary, and salinity levels have increased in this area (Levings, 1980; Pomeroy and Stockner, 1976). In addition, sediment studies have shown that the delta east of the Training Dike was no longer accreting the pre-disturbance rate. Studies of grain sized in the west, central, and east deltas show that the sediment in the east and central areas has become more influenced by tidal action rather than fluvial actions, which would have been expected in this type of estuary (Levings, 1980). The water from 1970 onwards clearly appeared to not move through the culverts effectively and the environment in the central and east deltas was changed from the characteristic fjord-type estuary.

The addition from 1995 to 2007 of new culvert crossings at key locations along the dike (Figure 7) were intended to improve overall circulation and function of the estuary by improving water flows between the Squamish River and the Central Estuary. The culverts have proved effective in allowing for water exchange between the brackish waters of the Central Estuary and the fresh water of the Squamish River and, to a lesser degree, allow some transport of sediment during spring freshet.

WATER QUALITY AND SALINITY IN THE SQUAMISH ESTUARY

Water quality studies undertaken in the Squamish Estuary occurred in the early 1970s as part of the Squamish Estuary Management Plan Habitat Work Group. From September 1972 to September 1973 and February 1974 until January 1975, measurements were taken on turbidity, temperature, salinity, pH, and DO on the Squamish River delta to determine the effects of the river diking and industrial development on benthic communities (Levings, 1978).

The primary source of salt water input to the Squamish Estuary is the Strait of Georgia (Howe Sound) where salinity levels are generally below 29 ppt. This is heavily influenced by the volume of fresh water flowing down through the Squamish River and Stawamus River into upper Howe Sound that provide the brackish mixture of water that forms estuarine habitat. Wind also has an influence on the mixture of the lighter fresh water that sits over top of the denser salt wedge (Figures 33, 34, and 35).

As part of the 1981 study, the salt wedge of the west delta was found to be less saline than the East and Central deltas and the Mamquam Channel due to the influence of the Training Dike (SEMP Habitat Work Group, 1981).

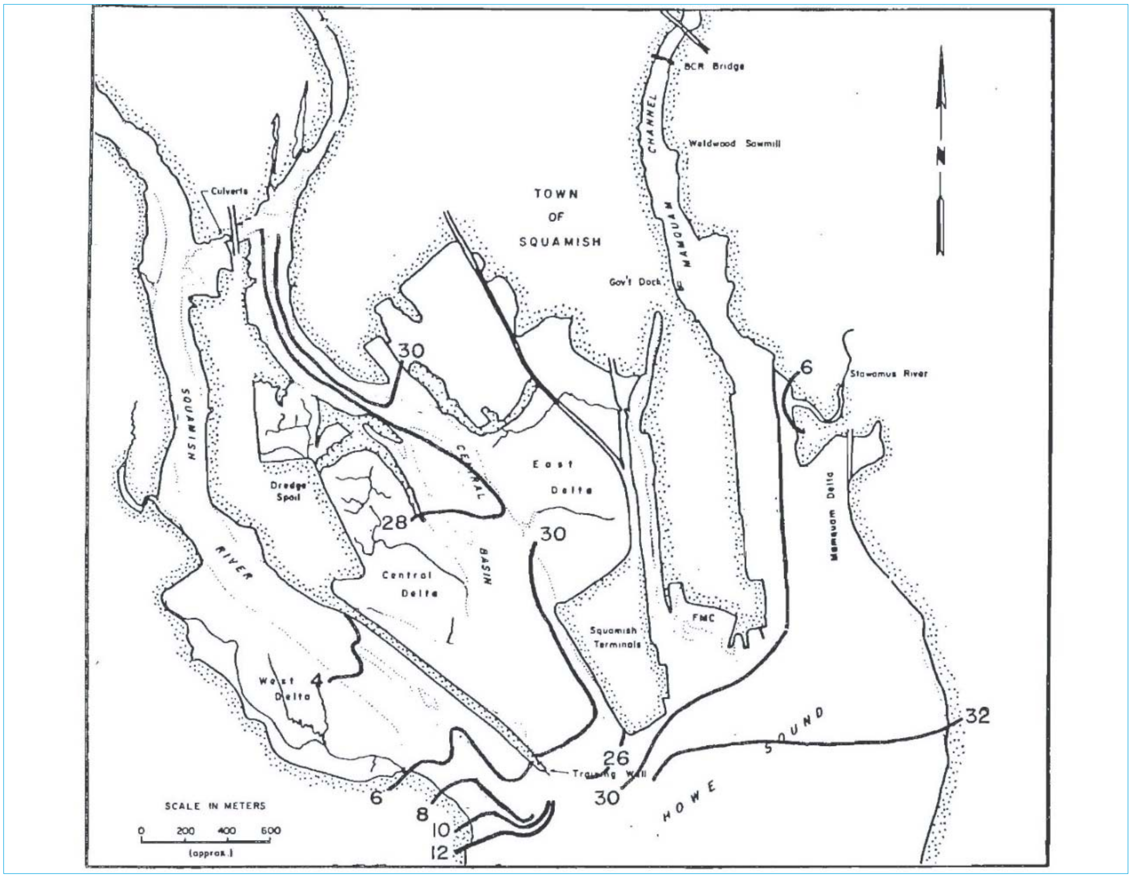


Figure 33. Squamish River Estuary Surface Distribution of Salinity, February 1973 (SEMP Habitat Work Group, 1981)

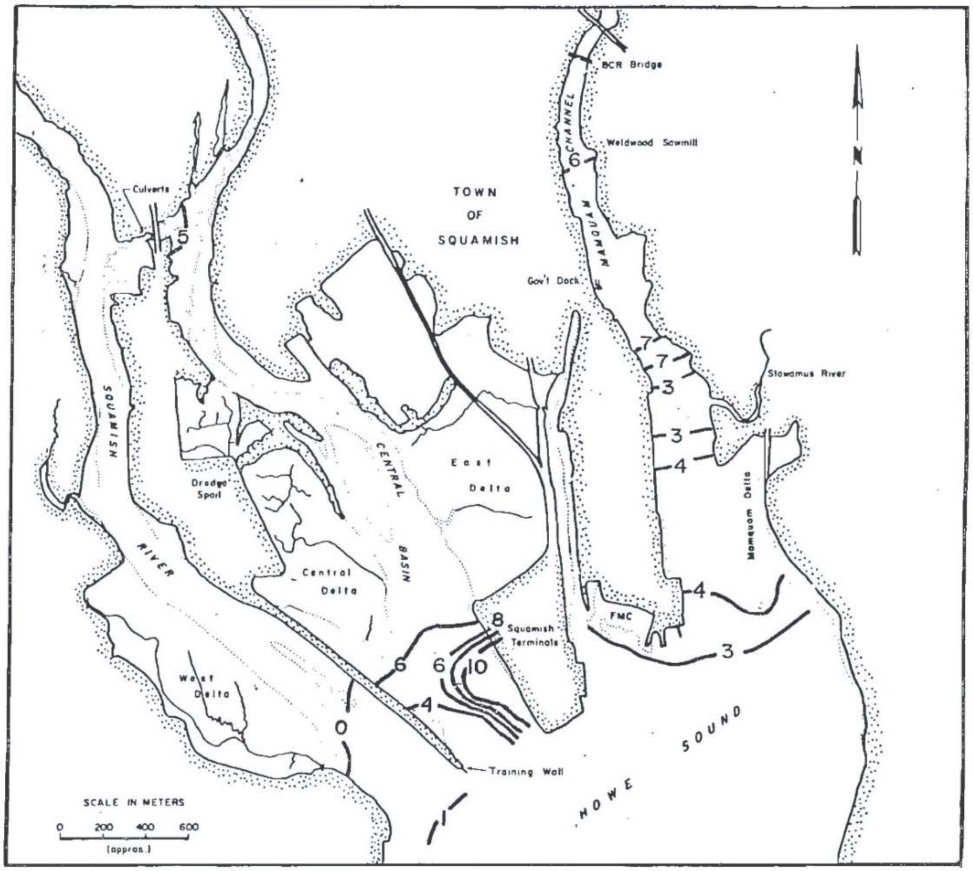


Figure 34. Squamish River Estuary Surface Distribution of Salinity, December 1974 (SEMP Habitat Work Group,1981)

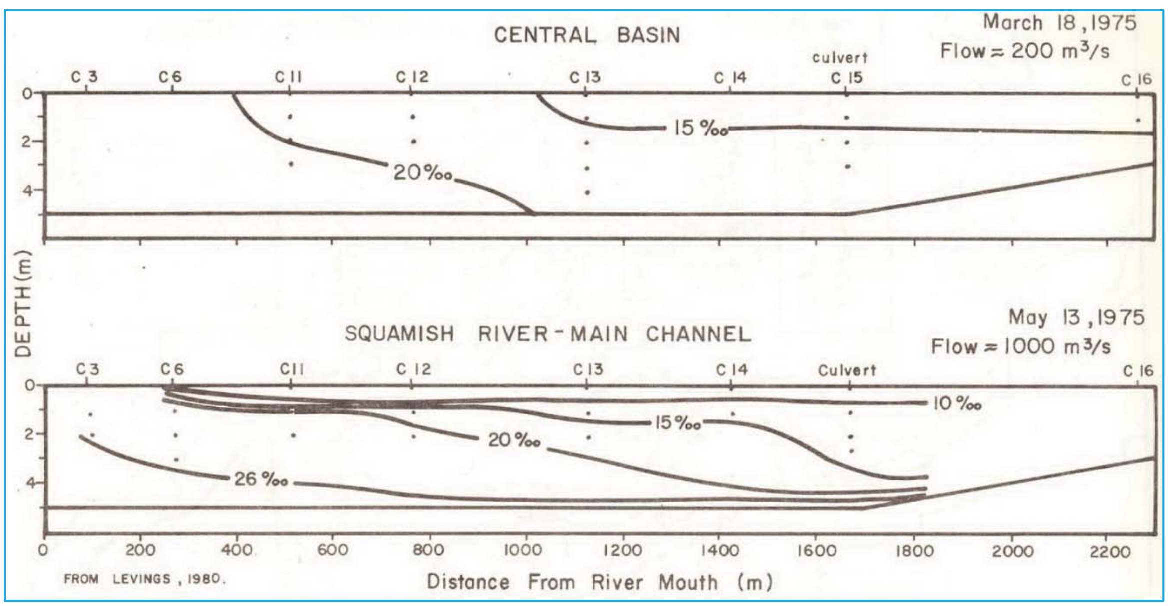
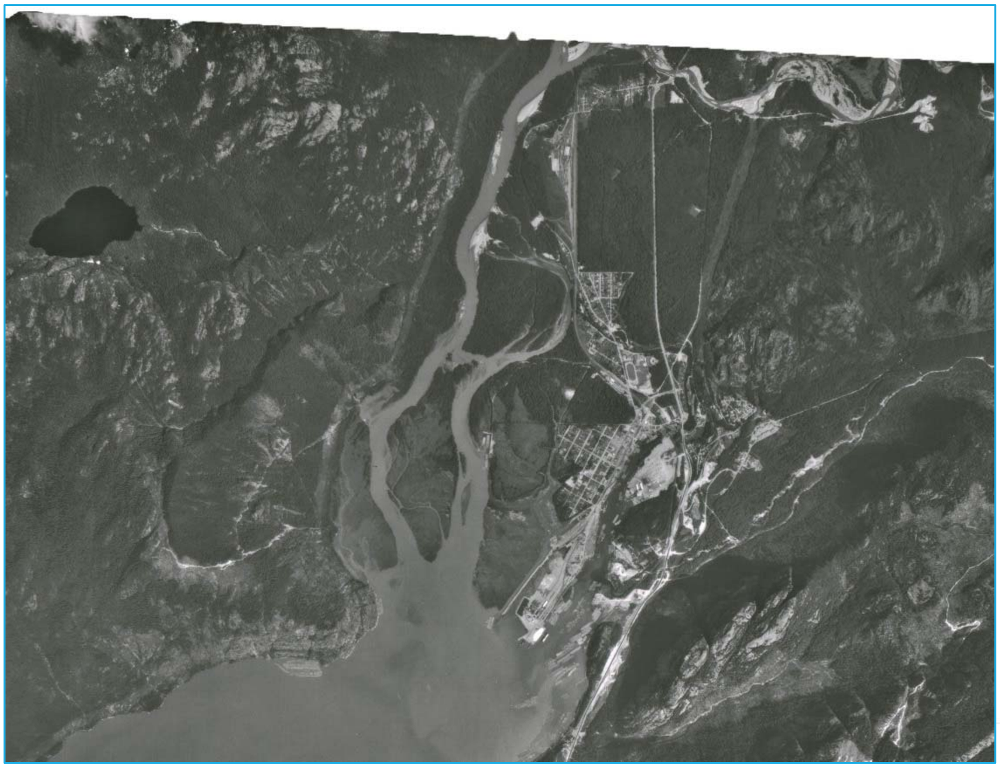


Figure 35. Vertical salinity profiles in Central Basin and Squamish River main channel, March 18, 1975 (SEMP Air and Water Quality, 1981)

APPENDIX 4: AERIAL IMAGERY FROM 1930 TO PRESENT DAY

Aerial Photo 1. 1930

Aerial Photo 2. 1954



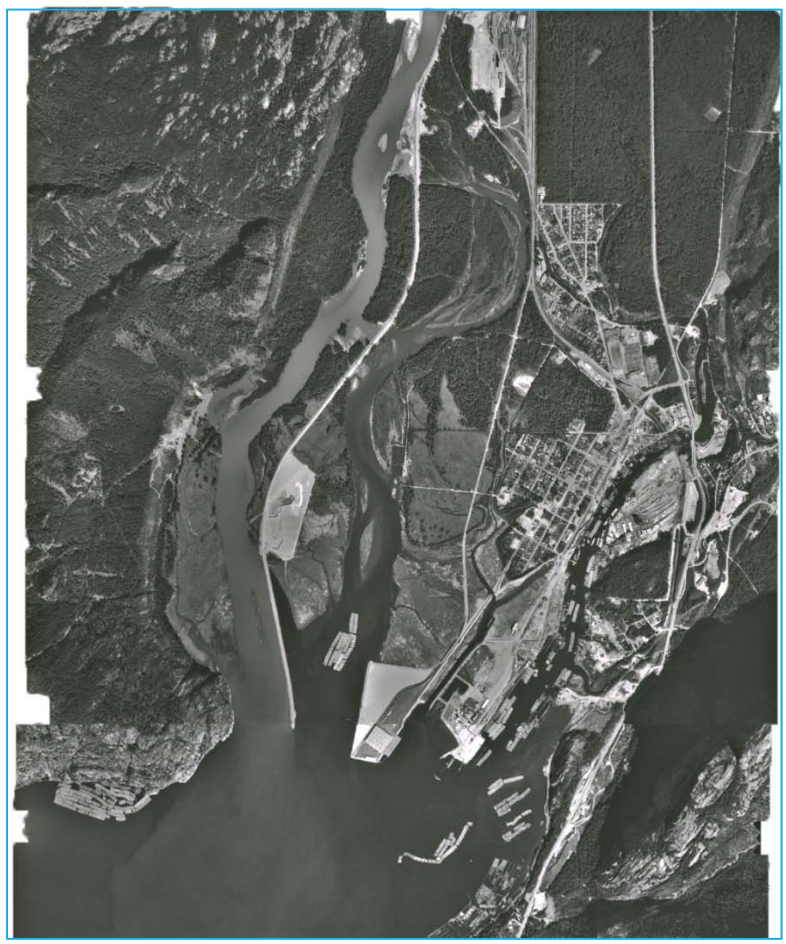
Aerial Photo 3. 1969

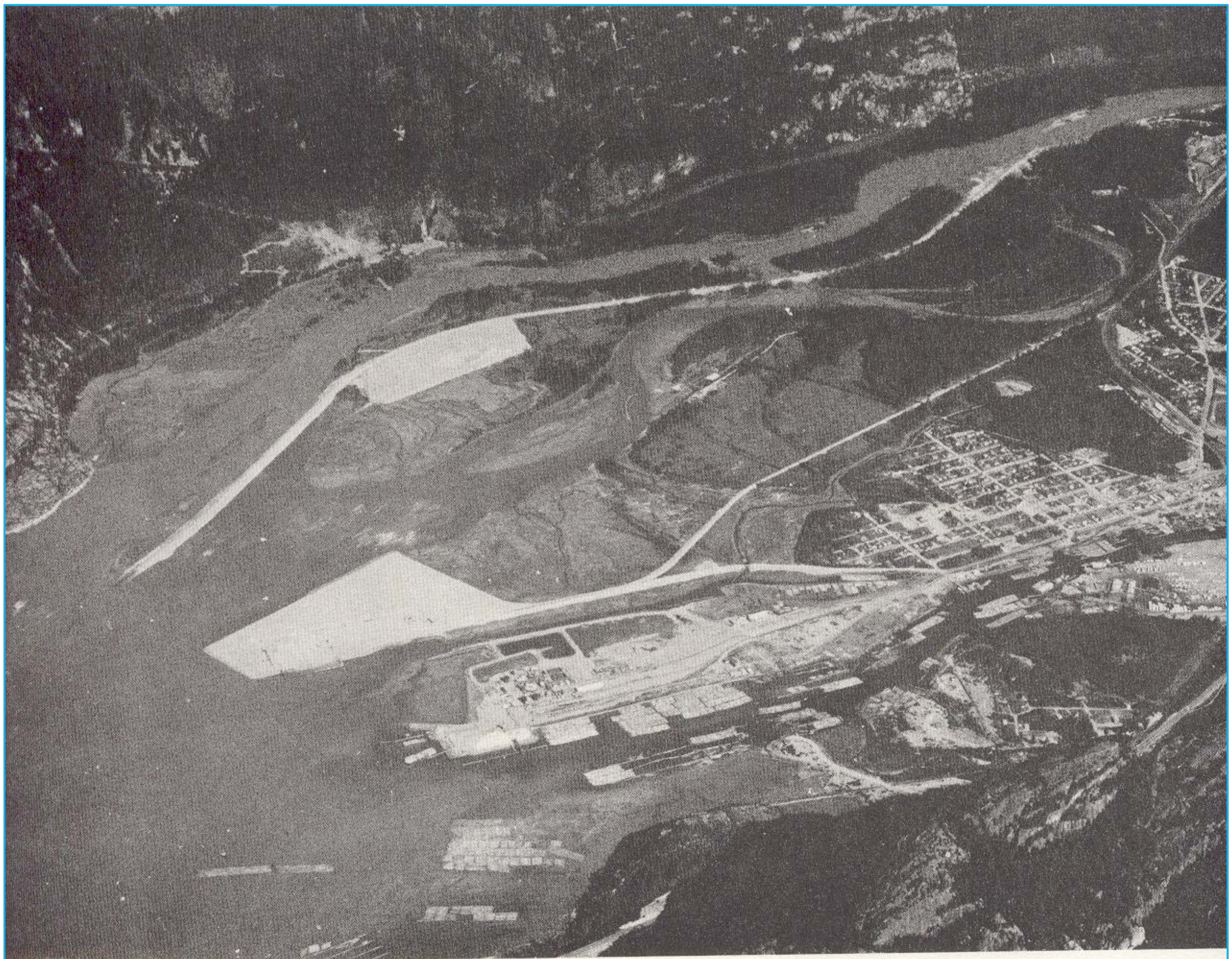
(above)

Aerial Photo 4. 1973

(right)

Note construction of Training Dike in lower photo



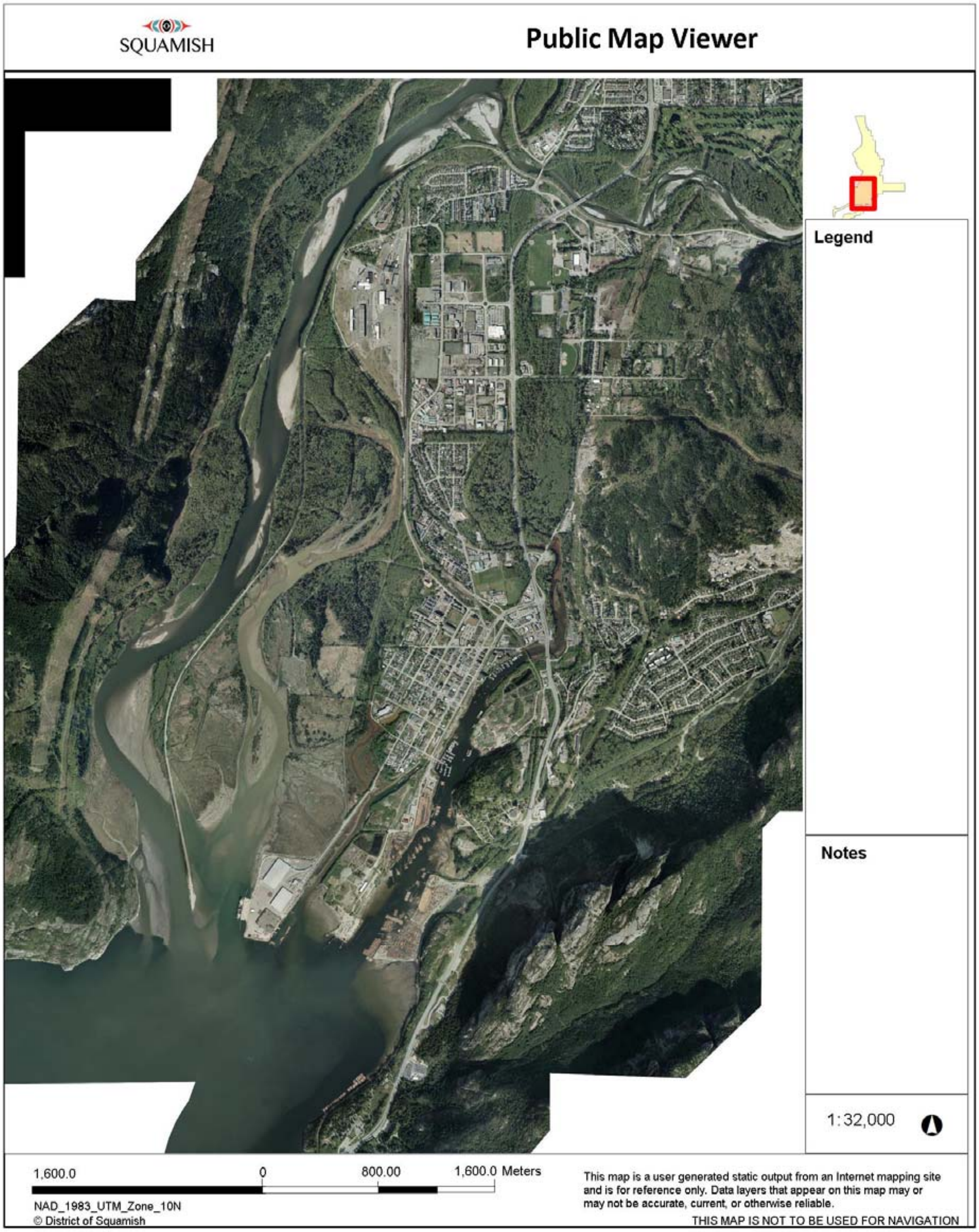


Aerial photograph of the Squamish River estuary, July 21, 1972.

Aerial Photo 5. 1972

Photo 6. 1999

Photo 7. June 2018. View from the Sea to Sky Gondola (photo credit: E. Tobe)



2016 imagery of Squamish (District of Squamish map viewer)

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