A Historical Marsh Vegetation Composition Comparison between Five Fraser River Foreshore Marshes

by

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Abstract

A full composition study of some key Fraser River foreshore marshes, Boundary Bay, Brunswick Point, Westham Island, Lulu Island, and Sea Island, had not been done in several decades, during which a large-scale marsh recession event occurred at two of the marshes. The vegetation composition is measured in this study with relation to soil water, soil pore water salinity, and elevation. The results in this study show a shift in the vegetation composition in some areas of the Lulu Island marsh, with the other marshes remaining relatively similar to historical data. The plant species' tolerance to soil water, soil salinity, and elevation vary in each marsh, illustrating the need for individualized restoration plans for each marsh. Conserving and restoring these marshes is critical in light of the many changes in the Fraser River delta, including sea level rise, increased geese populations, altered sediment regimes, and urbanization.

Keywords: Brackish marsh; salt marsh; vegetation composition; salinity; elevation; Fraser River

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Glossary

Salt marsh	A marsh primarily influenced by sea water
Brackish marsh	A marsh influenced by both sea water and fresh water
Foreshore	The area between the high and low tide mark
Sturgeon Bank	An area of intertidal marsh in the Fraser River delta that includes Sea Island and Lulu Island
Roberts Bank	An area of intertidal marsh in the Fraser River delta that includes Westham Island and Brunswick Point

Chapter 1. Introduction

1.1. Background Information

There have been many anthropogenic changes to the intertidal environments in the Pacific Northwest in the last century, such as channelization, dredging, diking, jetties, river training structures, increased urbanization, and agriculture. Tidal marshes are highly productive ecosystems, and these changes can affect them greatly (Kirwan and Murray, 2008). The distribution of various vascular plants changes based on the salinity of the area and duration of tidal inundation, and distribution may change because of anthropogenic changes (Janousek et al., 2016; Shaw et al., 2006). For example, *Typha latifolia* prefers very low salinity environments, while *Distichlis spicata* is tolerant of high salinity, but also can grow in freshwater environments (Adams and Williams, 2004). Tidal marshes are complex ecosystems, and need to be studied carefully so that restoration activities can be done in areas where marshes have been, or will be lost.

Tidal marshes provide many ecosystem benefits and services, such as rearing and refuge habitat for fish and invertebrates, shoreline protection from storms, carbon storage, and filtering contaminants (Bakker et al. 2002). The Fraser River in British Columbia is among the world's largest salmon (*Oncorhynchus* spp.) bearing rivers, and many animal species within this river depend on tidal marshes for various stages of their life cycles (Levings et al., 1991).

Plant species can act as an indicator for what is happening in a marsh, whether it is regarding sediment and soil water, or salinity and inundation time (Janousek et al., 2016). This makes vegetation distribution and composition of the Fraser River tidal marshes an important parameter to measure and track over time.

The foreshore marshes off the coasts of Lulu Island and Westham Island are on the north and south sides, respectively, of the main arm of the Fraser River that have been identified as key brackish marshes within the Fraser River estuary. Recent work at Lulu Island and Westham Island has shown large-scale marsh recession (Balke, 2017). There are several hypotheses of potential drivers of change, including hydrology changes, salinity shifts, dredging, herbivory, and inundation time (Balke, 2017). The loss of these marshes has been documented through air photos and historical data, however, there has not been any research done into how these hypotheses for marsh recession have affected the vegetation composition of the marshes. Vegetation composition is an important parameter to investigate, as these regime shifts could influence where the vegetation is distributed, how dense it is, and how tall it grows (Sharpe and Baldwin, 2012).

My applied research project (ARP) is investigating how these vegetation communities have changed over the last several decades to provide a scientific basis for future ecological restoration efforts. I conducted vegetation transects over Sea Island, Lulu Island, Westham Island, Brunswick Point, and Boundary Bay, within the Fraser River estuary. I examined percent cover of the species present, stem density, and average plant height. I measured soil water and soil pore water salinity to explain why these plants are located where they are. This data was compared to historical studies done in the 1970's and 1980's. This data that I collected will contribute to the larger overall restoration plan for these marshes.

1.2. Objectives

The objectives of my ARP are as follows:

1. Contrast how soil parameters influence vegetation distribution, plant height, and density at the various marshes.

2. Compare plant composition and soil parameters to historic results to illustrate changes.

3. Indicate factors influencing plant distribution that will assist in restoration efforts.

1.3. Background – Review of Historical Studies

1.3.1. Yamanaka (1975)

The first relevant study was published by Yamanaka (1975). This study evaluated how much vegetation biomass was produced in Fraser River foreshore marshes. Yamanaka established 14 semi-permanent transects that were visited several times over the span of two years to evaluate several criteria regarding the vegetation and soil. The transects were at Sea Island, Lulu Island, Westham Island, Brunswick Point, and Boundary Bay. Yamanaka (1975) used a 1-x1-m quadrat to evaluate vegetation cover, and all vegetation was clipped. Soil pH, salinity, and organic matter were evaluated. From the dried plant material, dry weight, nitrogen content, lignin, and ash measurements were taken. It was found that *Schoenoplectus pungens* was the species with the highest presence, followed by *Bolboschschoenus maritimus*, *Carex lyngbyei*, and *T. latifolia* at the brackish marshes. Key species at the Boundary Bay marsh included *Sarcocornia pacifica*, *Triglochlin maritima*, *D. spicata*, and *Atriplex patula*. There was generally a decrease in biomass as one moved seaward from the dike to the low tide mark. Yamanaka also found that plant height decreased as distance from the dike increased. It was found that soil electrical conductivity generally decreased as distance from the dike increased. (Yamanaka, 1975).

1.3.2. Hutchison (1982)

A second relevant study was published by Hutchison (1982). Six evenly spaced transects were established in the foreshore marsh of Lulu Island. A 0.25-m^2 quadrat was placed 4 times around survey markers that were spaced every 50 m. All the vegetation was clipped and analyzed in the laboratory, for species weight percentage of the total biomass. A soil sample was also taken to calculate soil moisture. Once the soil sample hole was dug, it was allowed to fill with water before taking the salinity with a YSI meter. It was found that salinity was the lowest closest to the dike. The primary soil texture was silt, with some clay and sand. The highest amount of sand was found closest to the dike culverts. The low marsh had the lowest soil water content. It was found that three primary species, *S. pungens*, *B. maritimus*, and *C. lyngbyei*, together were 75% of the biomass collected. It was found that *B. maritimus* was more likely to be found in higher salinity areas, and *C. lyngbyei* was more likely to be found in lower salinity areas. (Hutchison, 1982).

1.3.3. Boyd (1983)

The third relevant study was published by Boyd (1983). This was a one-year preliminary study to get baseline information for future studies. The same six transects that were established by Hutchison (1982) were used in this survey, and samples were taken every 100 m. The information recorded at each station was 5 plant heights of the dominant species, surface water salinity, particle size of the top 1 mm, and moisture content. The same locations were visited several times over one year to monitor plant growth. It was determined that maximum growth was reached in mid to late July. It was found that there were no significant differences in plant growth among the six transects, and the top 1 mm particle size did not change over the year. The soil moisture was highest at the dike, and lowest at the low tide mark. (Boyd, 1983).

1.4. Fraser River History and Current Conditions

1.4.1. Changes in the Fraser River Delta

The Fraser River drains 232 000 km^2 of British Columbia (Church, 2017). It drains into the Pacific Ocean in Metro Vancouver through the North Arm, Middle Arm, Main Arm, and Canoe Pass (Church, 2017). Freshet occurs in May, June, and July (Church, 2017). The Fraser River delta formed 10,000 years ago after the last glaciers retreated, and after this formation, meandered significantly (Luternauer and Finn, 1982). Significant meandering causes an area to be dominated by wetland type plants (Luternauer and Finn, 1982).

Most of the sediment that is transported in the Fraser is Pleistocene valley fill from riverbanks (Church, 2017). The gravel portion of the sediment load is deposited in the gravel reach between Hope and Chilliwack, and the sand portion is deposited in the sand-bed reach, in the Fraser Valley (Church, 2017). Historically, much of the silt load was deposited on the delta front floodplains, but today, it is primarily carried out to sea with the clay load because of diking, channelization, and river training structures (Church, 2017). The way the sediment is deposited is dependent on the tide cycles. During a flood tide, the sediment is pulled more towards Sturgeon Bank (Leuternauer and Finn, 1982). This flow regime has resulted in Sturgeon Bank having more clay and silt sediments, and Roberts Bank having more silt and sand sediments (Leuternauer and Finn, 1982). There has been large scale removal of sand from the sand-bed reach by dredging to accommodate shipping (Church, 2017). This has resulted in less sediment being delivered to the delta-front marshes. This means that the marshes are not accumulating sediment and rising in elevation as they naturally would, which means they may not keep up with sea level rise and other changes (Church, 2017). It has been shown that the sediment accumulation rates at Sturgeon Bank was 51% less from 1964-81 than in 1954-1964, which is the most recently available data from a carbon study (Barrie, 2000).

The large, fast growing population in the Metro Vancouver area has led to dikes being built on the delta plain (Barrie, 2000). It is predicted that in the future, flood frequency will increase, which may lead to larger dikes (Church, 2017). In the early 1900's, there was no shipping access to the Fraser River. Since then, jetties and causeways have been built to maintain the dredged depth of the Fraser (Barrie, 2000). These structures are significant barriers to sediment accumulating on the delta front in the historical way (Barrie, 2000). Sturgeon Bank has been the most restricted from the Fraser River because of multiple jetties and channel training (Atkins et al., 2016).

1.4.2. Fraser River Influenced Estuarine Brackish Marshes

The four brackish marshes in this study are located at Sea Island, Lulu Island, Westham Island, and Brunswick Point (Figure 11). Brackish water is defined as having salinity between 0.5 and 30 ppt, but the Fraser River estuary brackish marshes have been noted as having surface water salinities lower than the upper limit of 30 ppt (Hutchison, 1982; Boyd, 1983). The Fraser River is a salt-wedge estuary, meaning that the salt water flowing upstream is underneath the freshwater flowing downstream, forming a curved boundary of fresh and salt water (Adams and Williams, 2004). The location of the salt wedge changes with the flow level of the river, with it going further upstream during low flow events (Adams and Williams, 2004). The variable salinity along the Fraser River, as it is a salt wedge estuary, influences how plants are distributed within the delta marshes, with each marsh having a unique distribution. There are pumping stations at some of the marshes that pump freshwater from the landward side of the dike to the seaward side of the dike. There are typically one or two plant species that dominate in each area of these brackish marshes, with the salinity typically increasing as distance from shore increases (Hutchison, 1982). Higher elevation areas of the marsh are usually higher diversity than the lower elevation areas, where monotypic stands are more common (Adams and Williams, 2004). However, the low marsh may become more diverse if it is located close to one of the arms of the Fraser River (Adams and Williams, 2004). The marsh at Lulu Island is partitioned into three sections: high, middle, and low marsh. The high marsh consists of *Agrostis exarata*, *D. spicata*, and *Potentilla anserina* (Hutchison, 1982). The middle marsh contains *C lynybyei.*, *T. maritima*, and *B. maritimus*. The low marsh contains *B. maritimus* and *S. pungens* (Hutchison, 1982). This abundance of each species may change at the other three marshes, but these species are common at all four.

1.4.3. Boundary Bay

Boundary Bay was connected to the Fraser River delta until 5500 years ago, when it was cut off by stabilizing sea levels (Figure 11) (Leuternauer and Finn, 1982). Boundary Bay receives primarily salt water, and is not as affected by the brackish water of the Fraser River estuary (Swinbanks and Murray, 1981). It is considered a true salt marsh. There are also some pumping stations at Boundary Bay that pump freshwater from the landward side of the dike to the seaward side. At Boundary Bay, the primary vegetation is made up of *D. spicata*, *T. maritima*, *A. patula*, and *S. pacifica* (Yamanaka, 1975). Boundary Bay has little variance in particle size, and this makes the effects of inundation time even across the marsh at Boundary Bay (Swinbanks and Murray, 1981).

1.4.4. Marsh Recession

There is 160 hectares of low elevation marsh that has disappeared off of Lulu Island after 1989 (Balke, 2017). There has also been a part of the marsh at Westham Island that has receded (Balke, 2017). This disappearance has been mapped, but there has not been any documentation as to how the plant communities have been affected. The area of the marsh that has recessed was historically *S. pungens* and *B. maritimus*, but it is not known if all the zones have shrunk further landward, or if the lower sections are simply missing. My study is, in part, helping to quantify the marsh recession further.

1.5. Factors Affecting Plant Distribution

There are several factors that affect plant distribution within foreshore marshes. Four that have been identified as key factors are interstitial salinity, elevation, soil moisture, and soil particle size (Hutchison, 1982).

1.5.1. Interstitial Salinity

Salinity is a measure of all the salt ions that are present in water. Salinity is an important factor in determining plant distribution, as certain species are more tolerant to salt. In river estuary marshes, the highest salinity of surface water typically occurs after freshet flow (Ewing, 1986; Church, 2017). In the Fraser River, this means that the highest surface water salinity affecting the plant growing season occurs in July and August. As my data collection occurred during this time period, I will have captured some of the higher salinity values affecting the plant growth. Elevated salinity levels can negatively affect plants in several ways, including preventing germination, and slowing nutrient uptake (Belleveau, 2012). Plant species within the marshes are either obligate or facultative halophytes. Obligate halophytes typically have lower growth than facultative halophytes (Parida and Das, 2005). Facultative halophytes are able to grow best in the freshest water, but can tolerate higher salinity levels (Parida and Das, 2005).

There are several factors influencing salt accumulation, and a primary one in the high marsh is temperature (Wang et al., 2007). Higher temperatures can increase salt concentration through evaporation, especially in areas that are exposed for longer (Patridge and Wilson, 1989). Soil pore salinity is often higher than surface water salinities, as salt has the opportunity to accumulate in the soil (Wang et al., 2007).

1.5.2. Inundation Time/Elevation

Inundation time of different marsh zones typically corresponds with the elevation of the area. Inundation time is a limiting factor of plant distribution of the Fraser River delta front marshes, and has also been found to be a primary contributing factor in other west coast of North America foreshore marshes (Adams and Williams, 2004; Belleveau, 2012).

1.5.3. Soil Water

Soil water has been identified as one of the factors that limits plant distribution in intertidal marshes (Hutchison, 1982). It has been found that soil water is linked with soil particle size. Sediment grain size influences the amount of moisture held during low tide periods. It has been observed at Lulu Island that the high amount of fine sand in the low marsh results in fast draining of the substrate (Hutchison, 1982).

1.5.4. Soil Particle Size

Particle size can play a key role in plant distribution. In intertidal marshes, usually particle sizes decrease as elevation increases (Swinbanks and Murray, 1981). In the higher elevations of the marshes, grain size can change where certain plants are distributed (Swinbanks and Murray, 1981). It has been suggested that both soil moisture and texture play a secondary role in determining plant distribution (Patridge and Wilson, 1989).

1.6. Richness, Diversity, and Evenness

Richness, diversity, and evenness are all important measures that describe the distribution of plant species. Richness is the number of species present within a defined area (Sharpe and Baldwin, 2009). In tidal marshes, species richness generally increases as one increases in elevation (Sharpe and Baldwin, 2009). Evenness is a measure of how the plant species are distributed proportionally. A sample with equally proportioned plant species will have higher evenness than a sample with one species with higher proportion than other species. Diversity is a measure that takes into account both richness and evenness. There are several different ways to calculate diversity. In this study, the Shannon Diversity Index was used. In this index, a higher value indicates higher diversity.

1.7. Key Plant Species Characteristics

1.7.1. *Schoenoplectus pungens* (Common Three-Square Bulrush)

S. pungens has been previously called *Scirpus americanus*. In brackish marshes *S. pungens* is often found as a large monotypic stand, but may also be found as small clusters in fresher or more saline environments (Adams, 2002). This colonial plant needs mean growing season salinities of 10-15 ppt, but in the Fraser River, it is able to tolerate mean growing season salinities of up to 20 ppt (Hutchison, n.d.). This plant typically occupies the leading edge of the foreshore brackish marshes in the Fraser River estuary

(Adams, 2002), (Figure 1). It is typically associated with *C. lyngbyei*, *B. maritimus*, *Juncus balticus*, and *Schoenoplectus tabernaemontani* (Adams 2002). This plant is often grazed and grubbed by snow geese extensively (Adams, 2002; Boyd, 1995). *S. pungens* was used by certain First Nations as a basket weaving material (Pojar and MacKinnon, 1994).

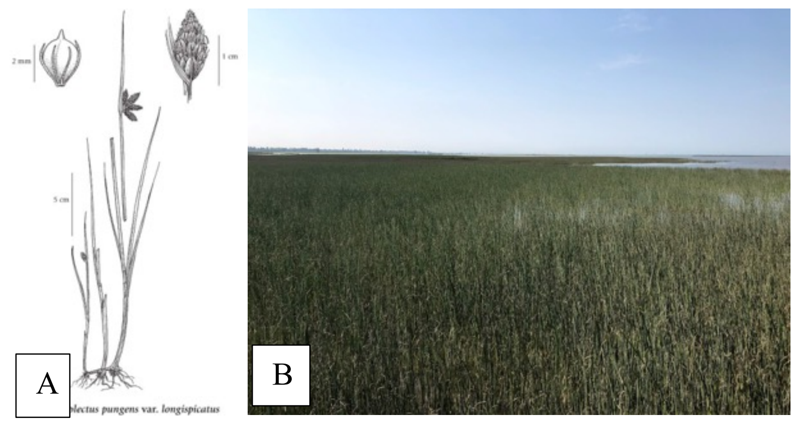

Figure 1. Diagram (A) showing the stem structure, seed head, and seed anatomy of *S. pungens* (Douglas et al., 2001), and a photo (B) of a stand of *S. pungens* at Lulu Island in July 2018 (photo by Janelle Bode).

1.7.2. *Bolboschoenus maritimus* (Seacoast Bulrush)

B. maritimus (Figure 2) is a sedge that occurs within the brackish marshes of the Fraser River delta. *B. maritimus* forms ramets; genetically identical plants that are connected underground through tubers and rhizomes to enable resource sharing among individuals (Charpentier et al., 1998). It is typically found in the low and mid elevations of the marsh (Adams, 2002). *B. maritimus*, along with *S. pungens* forms an important component of the leading edge of the marsh (Adams, 2002). It is also associated with *C. lyngbyei*, *S. tabernaemontani*, and *T. maritima* (Adams, 2002). *B. maritimus* was used for basket weaving as well, and was also used to decorate clothing articles and in cooking processes (Pojar and MacKinnon, 1994).

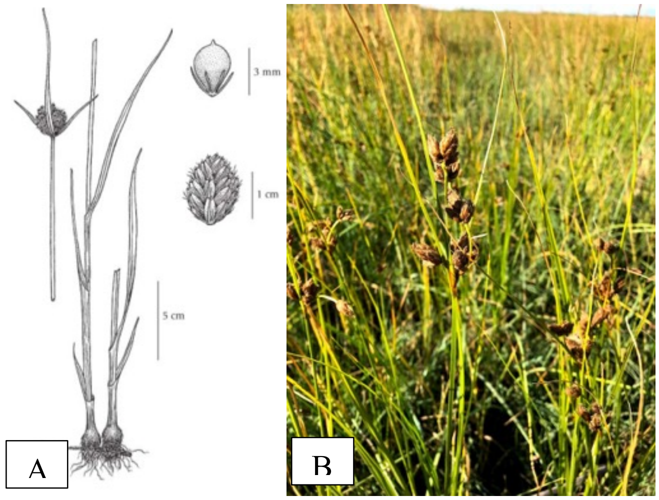

Figure 2. Diagram (A) showing the stem, seed, and root structure of *B. maritimus* (Douglas et al., 2001), and a photo (B) of a seed head of *B. maritimus* at Sea Island in August 2018 (photo by Janelle Bode).

1.7.3. *Carex lyngbyei* (Lyngbye's Sedge)

C. lyngbyei (Figure 3) is a common species in brackish and fresh marshes (Adams, 2002). It typically grows in lower salinity environments (Adams, 2002). *C. lyngbyei* needs substrate flushing to promote germination (Hutchison, n.d.). It is expansive, often forms monotypic stands, and has a distinct yellow-green colour. This plant forms significant root mats that are resistant to erosion (Hutchison, 1982). Because it is resistant to erosion, it often forms small channels within the marshes. It is often associated with *S. pungens*, *Typha latifolia*, and *S. tabernaemontani* (Adams, 2002).

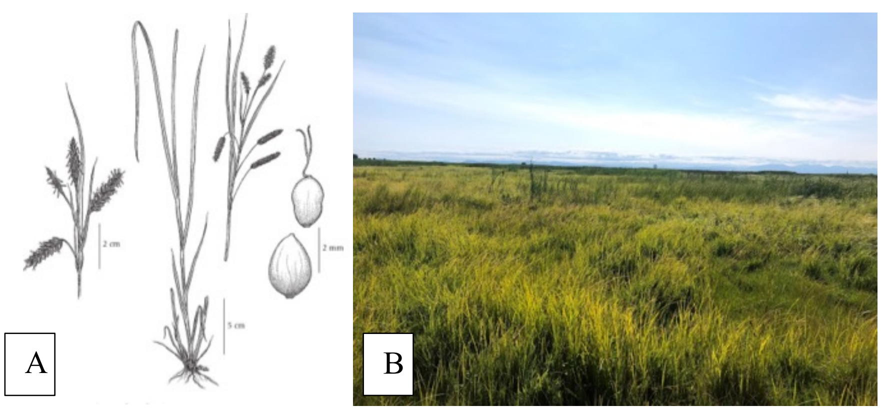

Figure 3. Diagram (A) showing stem seed head, seed, and root structure of *C. lyngbyei* (Douglas et al., 2001), and a photo (B) of a large stand of *C. lyngbyei* at Lulu Island in July 2018 (photo by Janelle Bode).

1.7.4. *Schoenoplectus tabernaemontani* (Soft Stem Bulrush)

S. tabernaemontani (Figure 4) is found in many aquatic ecosystems. In tidal marshes, it is found in low elevation, well drained areas and in high elevation, poorly drained areas (Adams, 2002). *S. tabernaemontani* is often found in pockets of the marsh that are relatively fresher than the surrounding areas (Hutchison, 1982). It is often associated with *Typha latifolia* in monotypic stands, and may also be found with *C. lyngbyei*, *B. maritimus*, and *T. maritima* (Adams, 2002). *S. tabernaemontani* was an important plant to Coast Salish peoples; it was used in the construction of shelters and furniture, and was used as currency for trading.

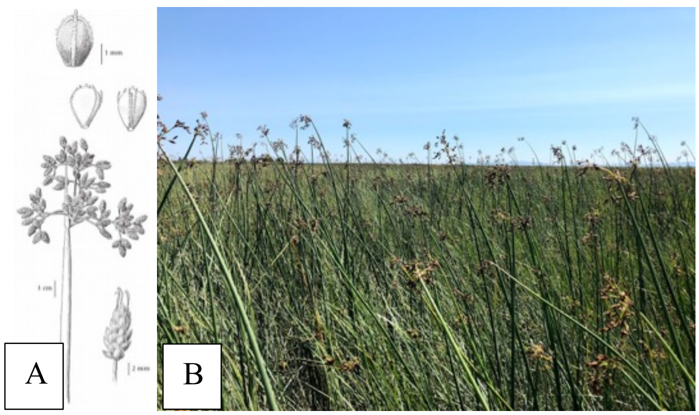

Figure 4. Diagram (A) showing *S. tabernaemontani* seed head and seeds (Douglas et al. 2001), and a photo (B) *S. tabernaemontani* at Westham Island in July 2018 (photo by Janelle Bode).

1.7.5. *Distichlis spicata* (Salt Grass)

D. spicata is a unique grass that grows in monotypic stands (Figure 5). It has a solid stem, which makes it easily identifiable from other grass species (Adams, 2002). It is often found in higher elevations of the brackish and salt marshes, and can tolerate high levels of salinity (up to 70 ppt at the subsurface level) because of specialized cells that excrete salt (Adams, 2002; Hutchison, 1982). It is often associated with *Sarcocornia pacifica* (Adams, 2002).

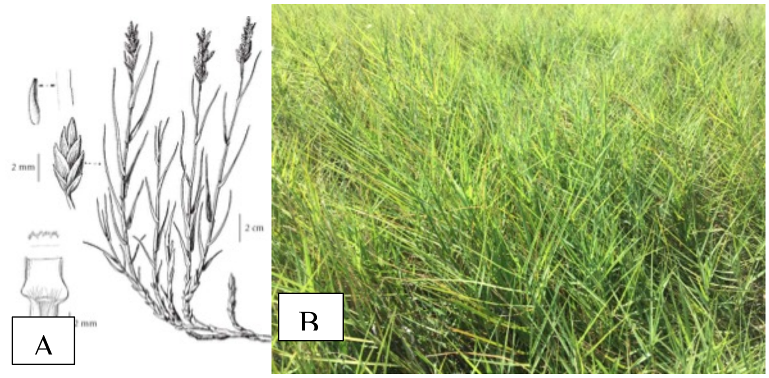

Figure 5. Diagram showing stems, leaves, seed heads, and seeds of *D. spicata* (Douglas et al. 2001), and a photo (B) showing a monotypic stand of *D. spicata* at Sea Island in August 2018 (photo by Krista Cawley).

1.7.6. *Potentilla anserina* (Silverweed)

P. anserina is a widespread species in the Rosaceae family. It has a vine-like growing pattern that allows it to cover large areas (Figure 6). It is typically found in high marsh areas (Yamanaka, 1975). The roots were eaten as a carbohydrate source (Turner and Kuhnlein, 1982). The young roots of the plant are harvested in the fall and cooked, often by steaming underground (Turner and Kuhnlein, 1982). *P. anserina* is not eaten in the same quantity now as it was in pre-colonization times, but this plant does have good nutritional value (Turner and Kuhnlein, 1982).

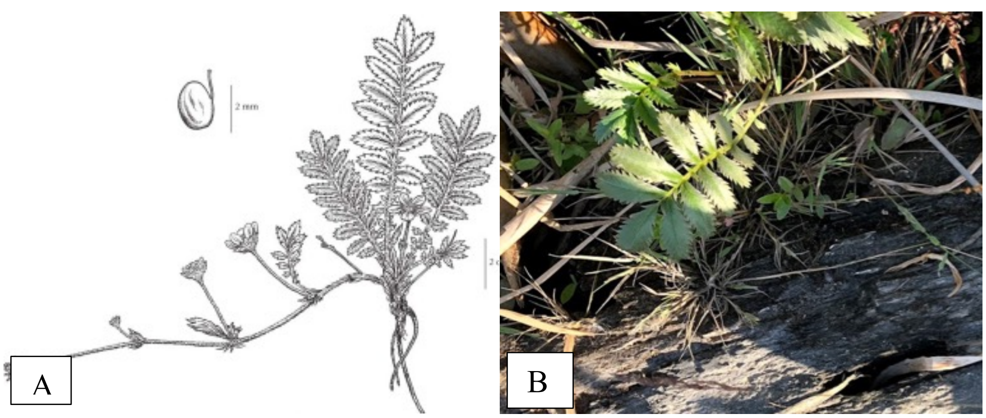

Figure 6. Diagram of *P. anserina* (A) showing leaves, flowers, roots, and vine-like growing pattern (Douglas et al., 2001) and a photo *P. anserina* at Lulu Island in July 2018 (photo by Janelle Bode).

1.7.7. *Juncus balticus* (Baltic Rush)

J. balticus is a rush that is often found in monotypic stands (Figure 7). It is typically found in brackish and freshwater marshes, usually in the mid and high elevations (Adams, 2002). *J. balticus* grows the best in well-drained soils (Adams, 2002).

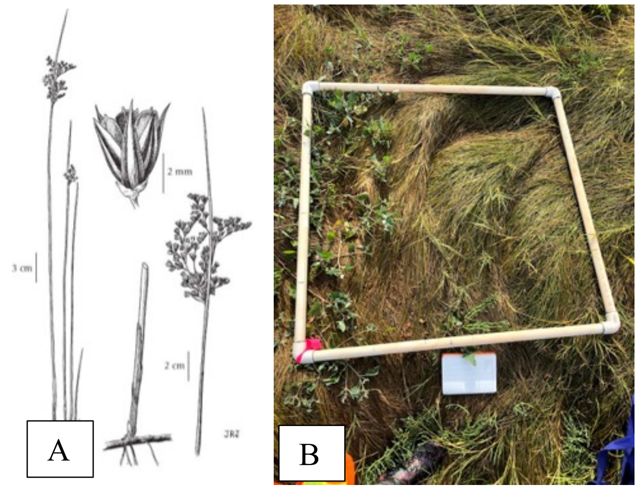

Figure 7. Diagram (A) of stem, root, seed head, and seed structure of *J. balticus* (Douglas et al., 2001), and a photo (B) of a monotypic stand of *J. balticus* at Boundary Bay in July 2018 (photo by Janelle Bode).

1.7.8. *Zostera japonica* (Japanese Eelgrass)

Z. japonica is an exotic eelgrass introduced from East Asia that colonizes tidal mudflats (Klinkenberg, 2018). The small plant size of *Z. japonica* and its seasonal reproductive strategy allows it to be a successful species within the Fraser River delta low- and mid-elevation marshes (Baldwin and Lovvorn, 1994). *Z. japonica* can tolerate higher elevation areas than *Z. marina*, which can occupy both tidal and intertidal areas, which means it may turn areas into eelgrass habitat that may not have been historically (Sutherland, 2013). The plant does not have a rigid stem, and lays flat when not submerged in water (Figure 8).

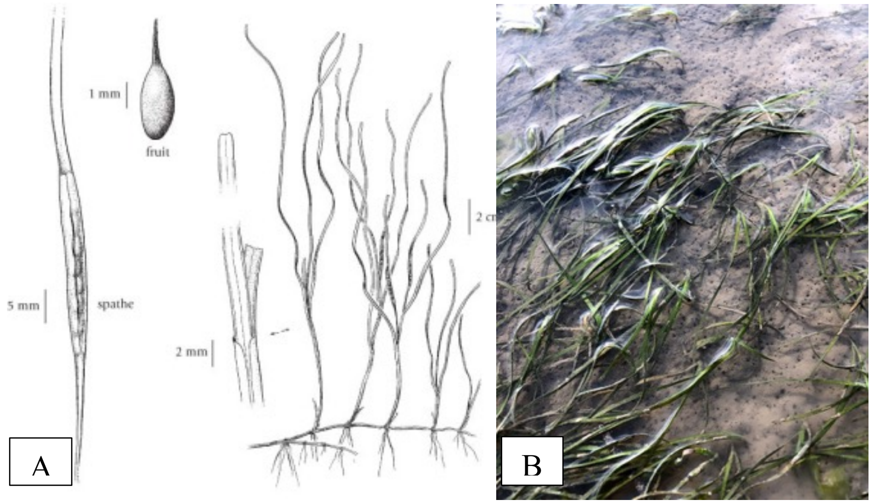

Figure 8. Diagram (A) showing leaves, seeds, and root structure of *Z. japonica* (Douglas et al., 2001), and a photo (B) showing a typical distribution of *Z. japonica* at Sea Island in July 2018 (photo by Krista Cawley).

1.7.9. *Sarcocornia pacifica* (Sea Asparagus/Pickleweed)

S. pacifica is a predominant species of salt marshes, and is often the most abundant species present there (Adams, 2002). It can form large mats in low elevation areas of the marsh (Adams, 2002). This species exhibits a characteristics horizontal and vertical growth pattern (Figure 9). This species has been commercially harvested in some areas on Vancouver Island and Boundary Bay as a food source (Hutchison and Smythe, 1988). Commercial harvesting of *S. pacifica* has potential to change the biomass produced of other species present nearby (Hutchison and Smythe, 1988).

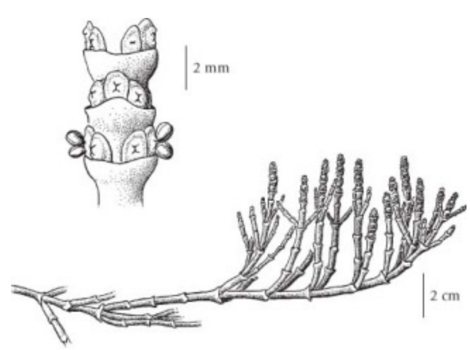

Figure 9. Growth pattern of *S. pacifica* (Douglas et al., 1998).

1.7.10. *Triglochin maritima* (Seaside arrowgrass)

T. maritima (Figure 10) is found in low elevation salt marshes, and in mid elevations in brackish marshes (Adams, 2002). It can tolerate a high level of inundation. This plant often occurs in small islands, with bare areas in between (Adams, 2002). It is sometimes associated with *D. spicata* and *S. pacifica* (Adams, 2002).

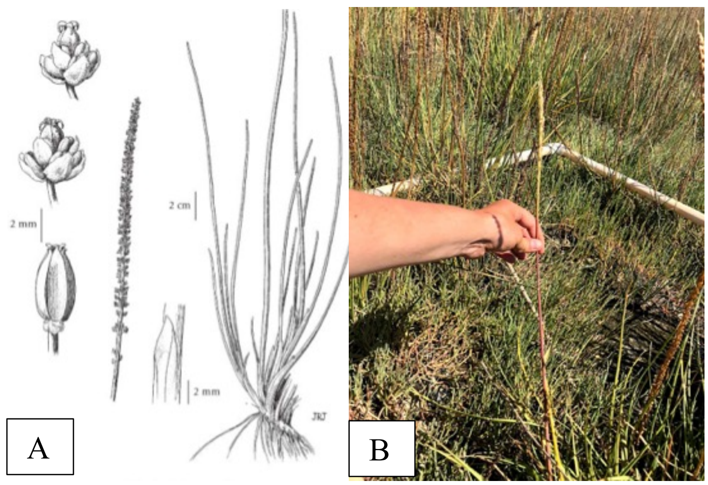

Figure 10. Diagram (A) showing leaf, stem, seed head, and seed structure of *T. maritima* (Douglas et al., 2001), and a photo (B) showing structure of *T. maritima* at Boundary Bay in July 2018 (photo by Janelle Bode).

Chapter 2. Methods

I created methods for evaluating plant composition, density, height, soil pore water salinity, and soil water at Sea Island, Lulu Island, Westham Island, Brunswick Point, and Boundary Bay within the Fraser River estuary. The majority of my study design was done by combining relevant methods from Boyd (1983), Hutchison (1982), and Yamanaka (1975). Additional methods were chosen based on equipment availability and ease of use in the field. Mapping was done in Google Maps and ArcGIS (version 10.6.1), and graphing and statistical analyses were done in R (version 3.5.1). For my study, I used 10 cm contour data, extrapolated from the most recently available LiDAR data (CGVD2013 vertical datum), to determine the elevation of each of my sample sites.

2.1. Transect Creation

I conducted 40 transects at five intertidal marshes at Sea Island, Lulu Island, Westham Island, Brunswick Point, and Boundary Bay to document the current vegetation composition (Figure 11). The surveys were conducted from July 16 - August 9, 2018, at or near low tide. The transects at Sea Island, Lulu Island, Westham Island, and Boundary Bay were spaced approximately 800 m apart, and at Brunswick Point they were approximately 300 m apart. Transects were conducted perpendicular to the dike. This resulted in most transects following an east-west direction. At Boundary Bay, transects were oriented in a north-south direction. Transects established by Hutchison (1982) and Boyd (1983) at Lulu Island were re-done in the same location. Transects established in Yamanaka (1975) were re-done in the same approximate locations, with new transects added to ensure representative coverage of each marsh.

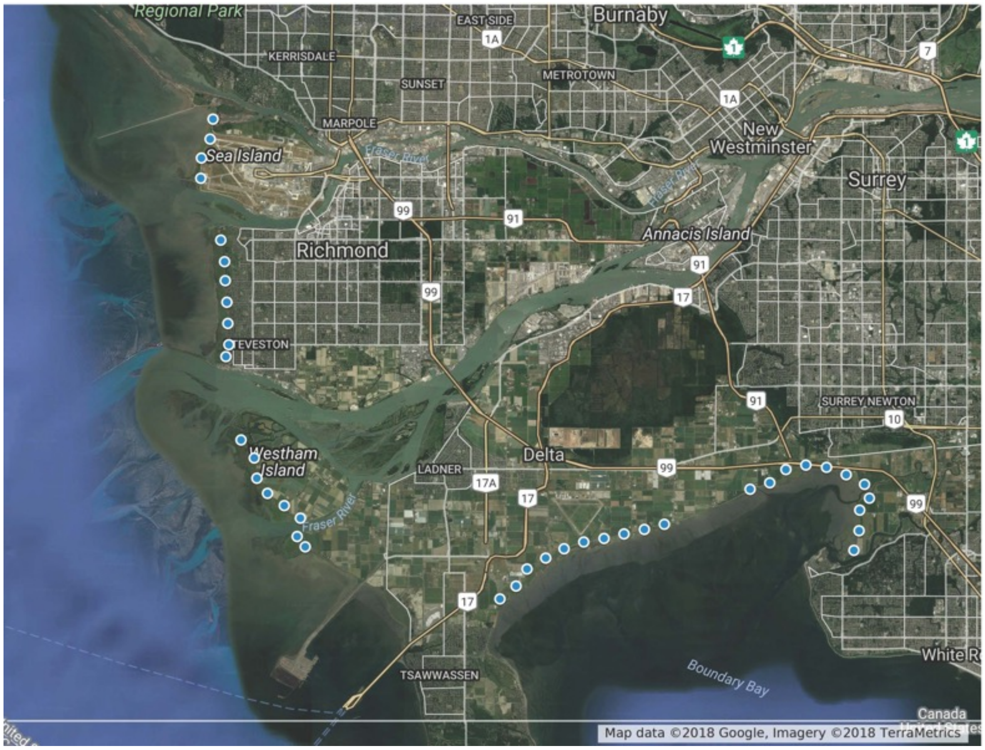

Figure 11. Locations of transects completed at Sea Island, Lulu Island (Richmond), Westham Island, Brunswick Point, and Boundary Bay in July and August 2018 within the Fraser River delta in British Columbia. Each blue marker represents the start of a transect (Google Imagery, 2018).

Four transects were conducted at Sea Island, 7 at Lulu Island, 6 at Westham Island, 2 at Brunswick Point, and 21 at Boundary Bay (Figure 12). At Lulu Island, the historical transects were re-done. Transect 7 at Lulu Island was newly created, and because it was not spaced 800 m apart like the other transects, it was not included in analyses. This transect will be important in the future because of the Steveston jetty breaches. At the other four locations, new transects were created. The first transect position was determined by a random number. The remaining transects were then spaced 800 m apart (Hutchison, 1982; Boyd, 1983). The length of the transect depended on marsh width at each location. Each transect was continued until the marsh had ended, defined as the end of upright vegetation, or where the transect ended in historical surveys.

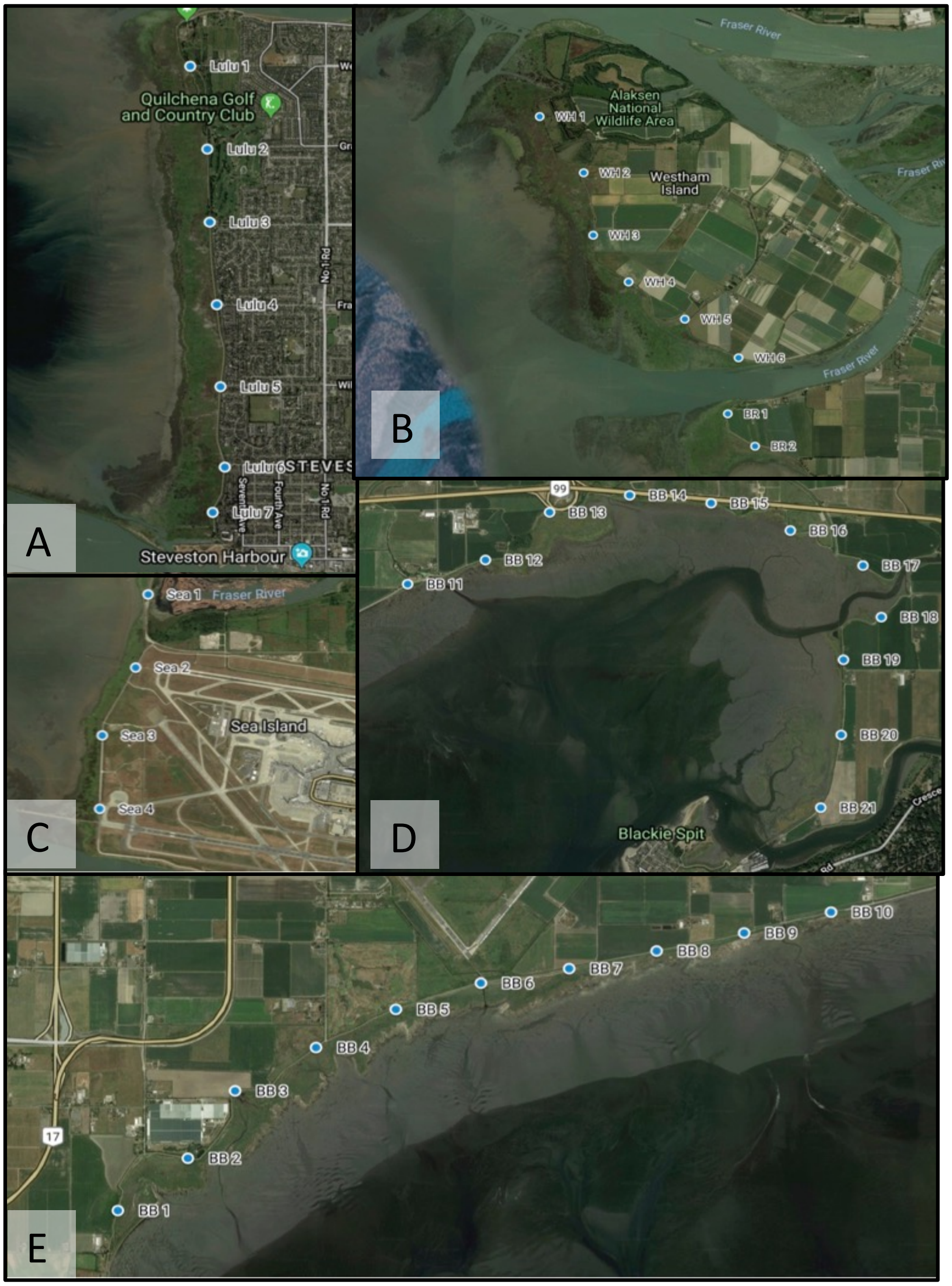

Figure 12. Detailed map with names of each transect labelled. There are seven transects at Lulu Island (A), six at Westham Island (B), two at Brunswick Point (B), four at Sea Island (C), eleven on the eastern side of Boundary Bay (D), and ten on the western side of Boundary Bay (E) in the Fraser River delta in British Columbia (Google Imagery, 2018).

2.2. Plant Survey

Quadrat (1 x 1 meter) surveys were done along each transect. At Westham Island, Sea Island, and Brunswick Point, a random number was used to determine where the first quadrat would be placed, and subsequent quadrats were placed every 100 m. The random number generator was set to give a random number between 50 and 100. It was chosen to start the transect surveys between 50 and 100 m from the dike to avoid the non-native, non-wetland plant species that often colonize the dike slopes (Yamanaka, 1975). At Lulu Island, the historical locations of where each quadrat was placed was replicated. Historical transect locations at Westham Island, Lulu Island, and Brunswick Point were not specific enough to exactly recreate the transect. At Boundary Bay, quadrats were spaced every 25 or 50 m apart, in accordance with Yamanaka's (1975) methods because the marsh is much narrower at Boundary Bay than the other four locations. Quadrat spacing of every 50 m was used as the standard at Boundary Bay. If four quadrats would not fit on a transect with 50 m spacing, then 25 m spacing was used. This methodology was used to ensure even coverage of each part of the marsh. The random number generator was then used to generate a number between 25 and 50 for the 50-m spaced transects, and between 12 and 25 for the 25-m spaced transects.

When the quadrat was first placed, plants were parted to get the quadrat as close to the ground as possible. This provided clear delineation as to which plants were within in the plot. A list of all species present in the plot was made, followed by an estimate of percent cover for each species. The percent cover estimates were done in layers, resulting in plots ending up with over 100% cover. This was done because there was often a layer of grass or other short species under a shrubby species, creating several layers of cover (Yamanaka, 1975).

The stem density and average height of the predominant plant species was recorded for each quadrat. The predominant plant species was defined as the one that had 50% or more cover within the quadrat, or the two species that added together totaled 50% or more cover within the quadrat. The stem density was measured by sub-sampling a 0.25 x 0.25 m area of the quadrat, and counting all stems of the predominant species within it (Boyd, 1983). The stem density was then extrapolated to a 1x1 m area. The average height of the predominant species was done by choosing the area within the quadrat that had the densest area of the predominant species. The five stems closest to the middle were measured to the nearest cm. The plant was measured by placing the measuring tape at the base of the stem at the ground, and measuring to the highest point on the plant. The plant was flattened or stretched out in order to measure the full length.

2.3. Soil Survey

Soil moisture, temperature, and electrical conductivity were measured around each quadrat location using a Decagon ProCheck 5TE meter. Soil moisture is measured in m^3 of water per m^3 of soil, and soil electrical conductivity is measured in dS/m. Three measurements were taken at each location and averaged to incorporate any variability in the soil. The soil probe was put in three locations randomly around the quadrat. The soil electrical conductivity results are not included in this paper, as the meter had technical difficulties measuring such high soil conductivity in the marshes. A soil sample from each quadrat location was collected using a 20 cm deep soil auger, and sealed in a plastic bag. Soil samples were further analyzed by placing in a coffee filter, and squeezing to obtain a drop of water to place on a refractometer. The salinity on the refractometer was read, giving a value for the interstitial soil salinity, following similar protocol as Belleveau (2012). I was unable to complete a full particle size analysis of my soil samples, so anecdotal observations will be used to make some inferences about the role soil particle size plays in plant distribution.

2.4. Statistical Methods

The plant heights of *S. pungens* and *B. maritimus* were collected in both 1981 and 2018 at Lulu Island. These values were averaged for both years and a t-test was performed between the heights of *S. pungens* in 1981 and 2018, and between the heights of *B. maritimus* in 1981 and 2018. The alpha value used was 0.05. A linear regression was done between elevation and several parameters (soil water, soil pore water salinity, diversity, evenness, plant height, and plant density) measured in the study.

There are three results sections on plant tolerance: elevation, soil water, and soil pore water salinity. In each of the sections, certain key predominant plant species were graphed in correspondence with each of the three parameters. On these graphs, each time the plant was encountered in the quadrat survey is included. Each marsh is graphed in boxplot format, with each datapoint shown.

Chapter 3. Results

3.1. Soil Water, Soil Pore Water Salinity, Plant Diversity, Plant Evenness, and Elevation, Salinity, and Soil Pore Water Salinity Tolerances of Predominant Plants

This section shows the results of the soil testing and plant sampling done in the field in 2018. It is organized so that each metric measured is grouped together for each of the five marshes. In many of the graphs, there is a linear regression line and R^2 value added. The evaluation of the significance of the R^2 value is divided into four categories: 0-0.25: insignificant relationship, 0.26-0.50: weak relationship, 0.51-0.75: medium relationship, and 0.76-1.00: strong relationship. The R^2 line represents the percentage of the variance that is captured by the linear regression line. The categories above are divided as such to ensure consistent descriptions of the relationships.

3.1.1. Soil Water

The soil water results showed the variability that soil water can have over the five marshes. At Sea Island (Figure 13), soil water increased as elevation increased, with a weak relationship R^2 value of 0.36. At Lulu Island (Figure 14), Westham Island (Figure 15), Brunswick Point (Figure 16), and Boundary Bay (Figure 17), soil water had an insignificant relationship to elevation (R^2 of 0.12). Lulu Island, Westham Island, and Brunswick Point both have relatively low soil water values across the marshes, with many values in the 0-12 m^3/m^3 range. Sea Island has a higher soil water range, with many values from 5-20 m^3/m^3. Boundary Bay has the highest soil water range, with values from 0-30 m^3/m^3. Boundary Bay also has more measurements than the other marshes, as half of the transects were located there because of the large area of marsh.

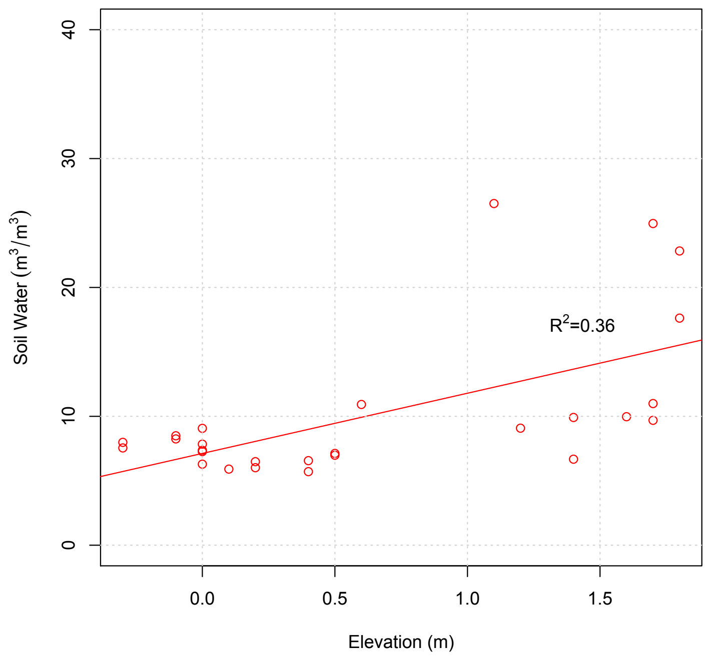

Figure 13. Sea Island soil water, graphed by elevation.

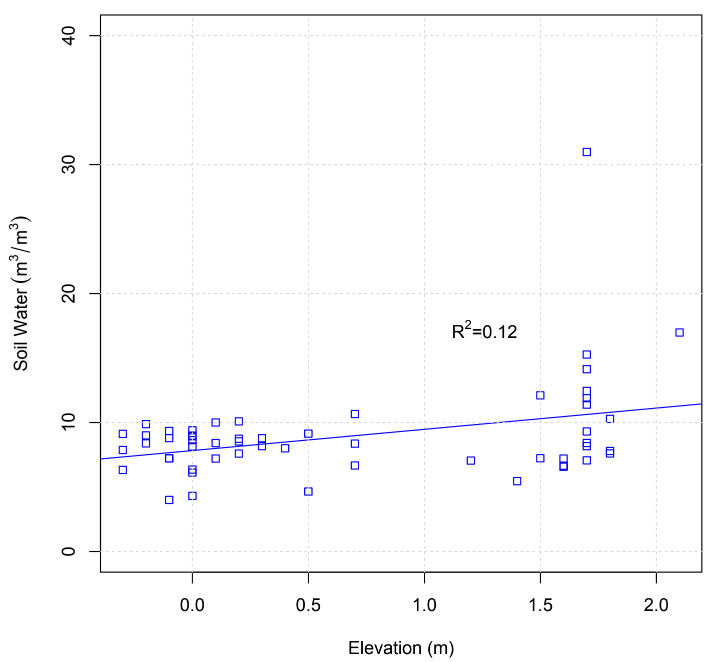

Figure 14. Lulu Island soil water, graphed by elevation.

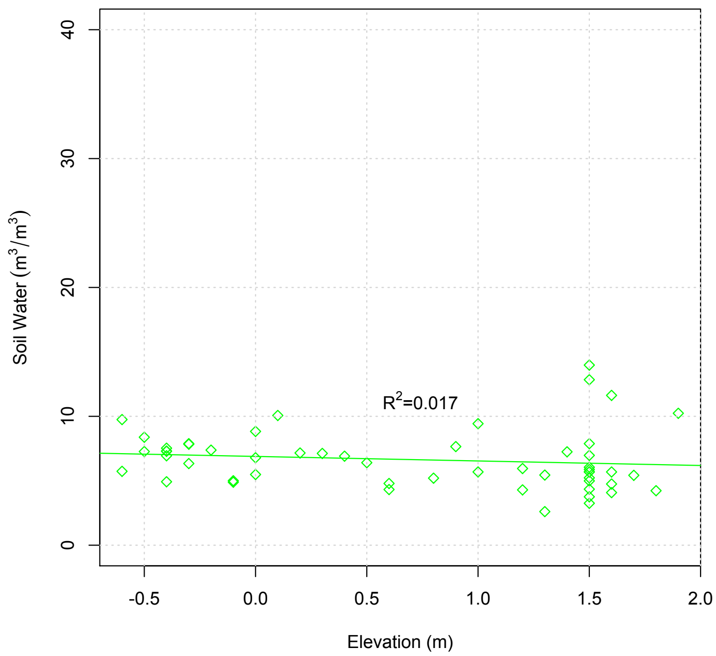

Figure 15. Westham Island soil water, graphed by elevation.

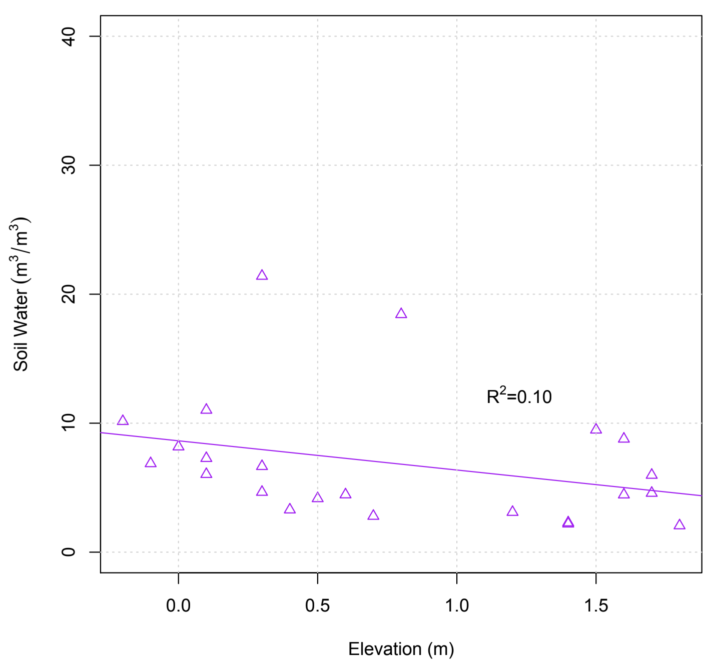

Figure 16. Brunswick Point soil water, graphed by elevation.

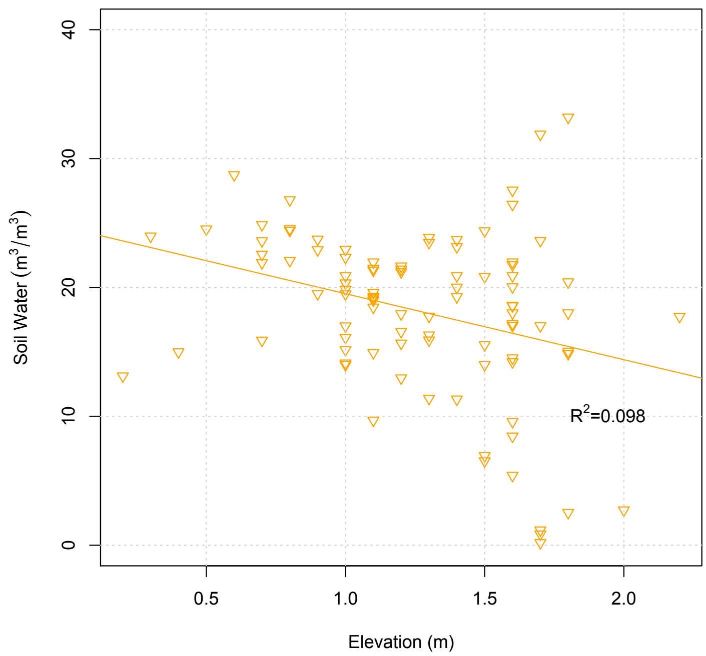

Figure 17. Boundary Bay soil water, graphed by elevation.

3.1.2. Soil Pore Water Salinity

At Sea Island (Figure 18), Brunswick Point (Figure 21), and Boundary Bay (Figure 22), the relationship between soil pore water salinity and elevation was insignificant. It is important to note that the y-axis in Figure 22 is different, as the soil pore water salinity at Boundary Bay was much higher than the other four marshes, with it ranging from 5-70 ppt. At Lulu Island, there was a medium negative relationship between soil pore water salinity and elevation, with an R^2 value of 0.63 (Figure 19). At Westham Island, there was also a medium negative relationship between soil pore water salinity and elevation, with an R^2 value of 0.57 (Figure 20). The soil pore water salinity value at Sea Island and Lulu Island was similar, with values ranging from 5-35 ppt. At Westham Island and Brunswick Point the soil pore water salinity was lower than at Sea Island and Lulu Island, with values ranging from 0-20 ppt.

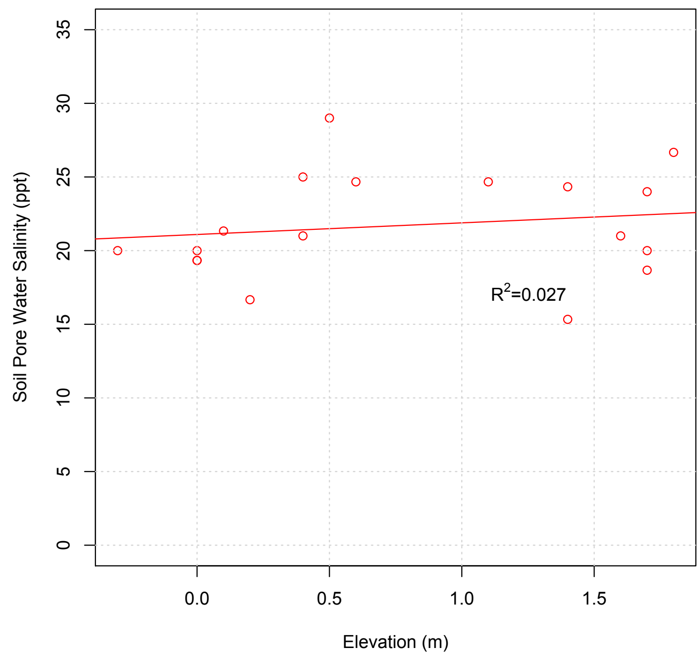

Figure 18. Sea Island soil water salinity, graphed by elevation.

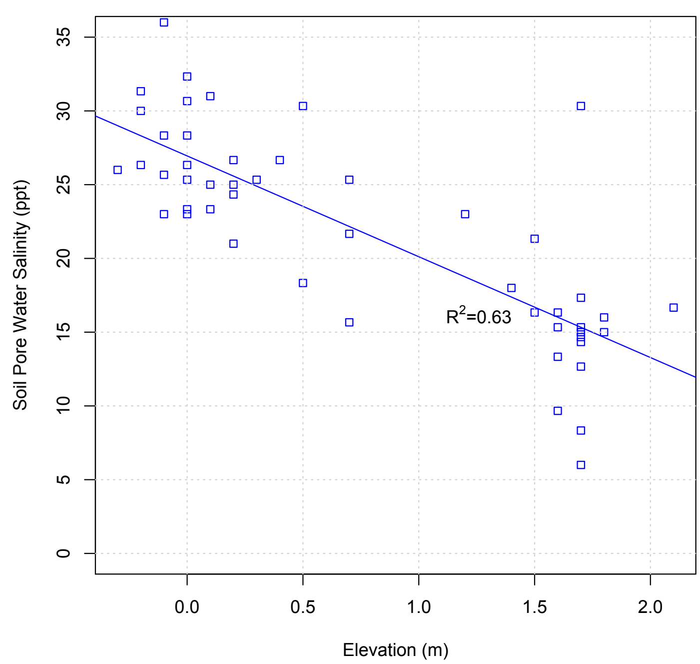

Figure 19. Lulu Island soil pore water salinity, graphed by elevation.

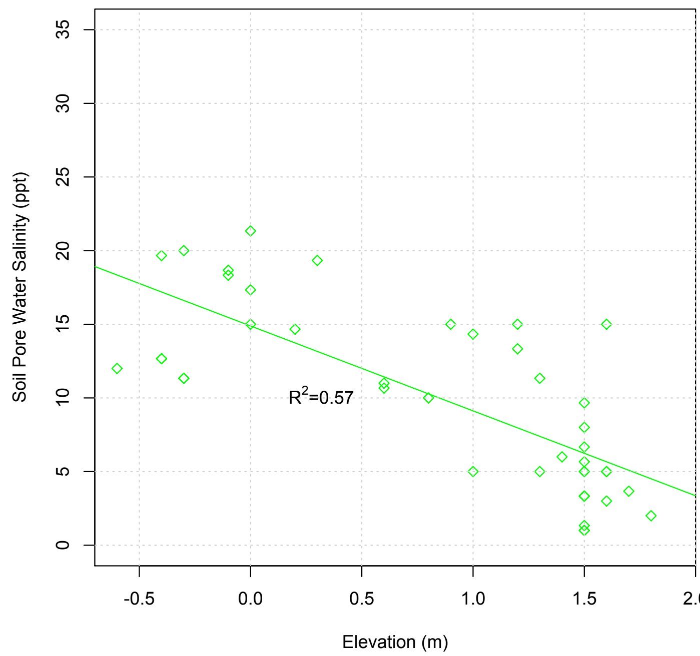

Figure 20. Westham Island soil pore water salinity, graphed by elevation.

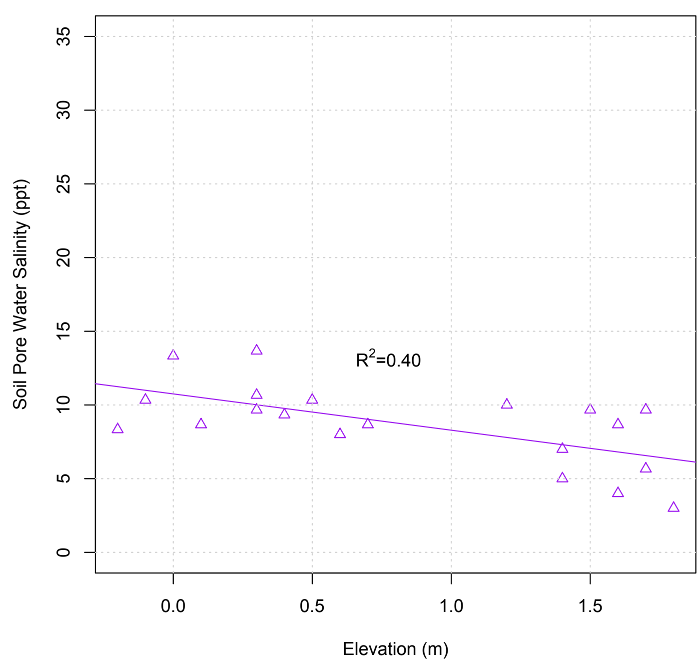

Figure 21. Brunswick Point soil pore water salinity, graphed by elevation.

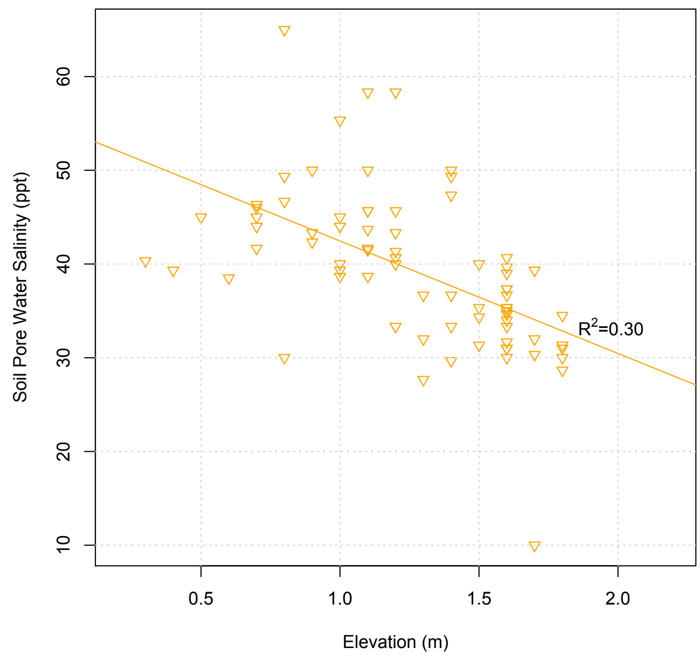

Figure 22. Boundary Bay soil pore water salinity, graphed by elevation.

3.1.3. Species Diversity

Species diversity plotted against elevation at all 5 marshes showed a general trend of decreasing diversity with decreasing elevation, with differing strengths of relationships. At Sea Island (Figure 23), Lulu Island (Figure 24), and Westham Island (Figure 25), the relationship between species diversity and elevation was weak. At Brunswick Point (Figure 26) and Boundary Bay (Figure 27), the relationship between diversity and elevation was insignificant. It is important to note that all five of the marshes had approximately the same range of diversity values. A diversity value of 0 represents that there was only one species present within the plot. Lulu Island and Westham Island had several points at lower elevations where the diversity value was 0.

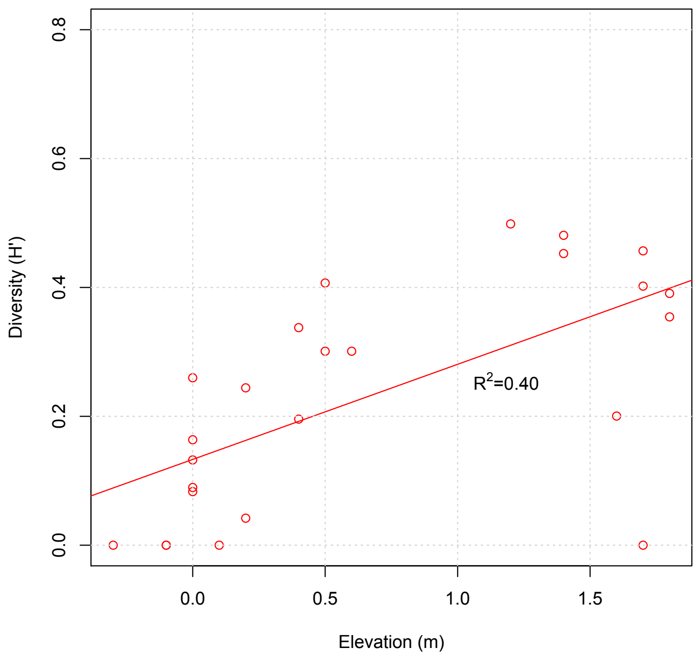

Figure 23. Sea Island species diversity, graphed by elevation.

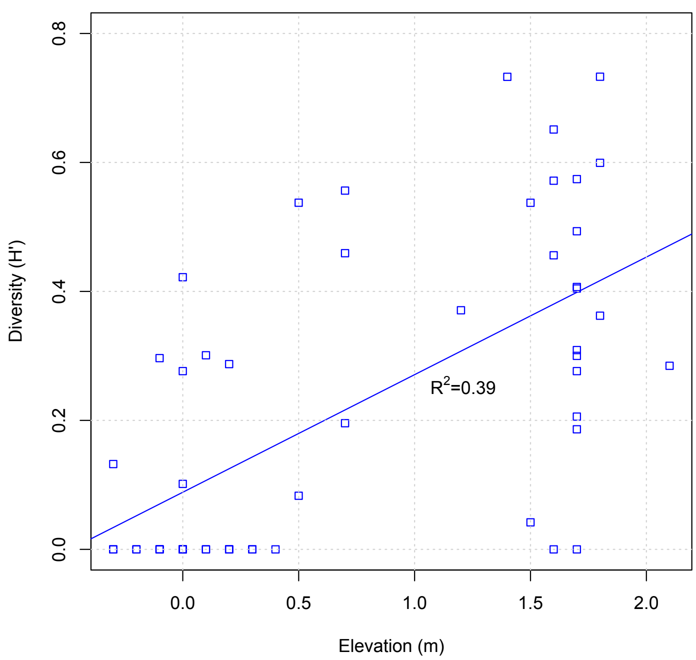

Figure 24. Lulu Island species diversity, graphed by elevation.

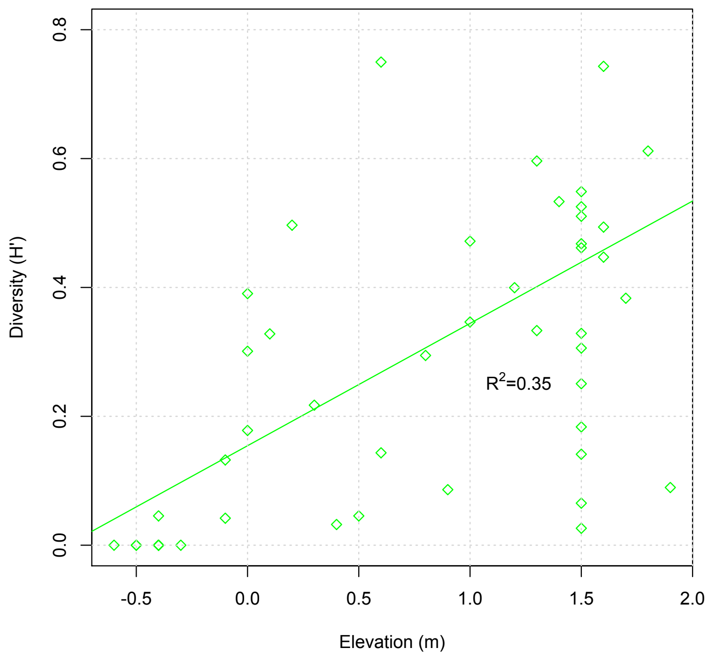

Figure 25. Westham Island species diversity, graphed by elevation.

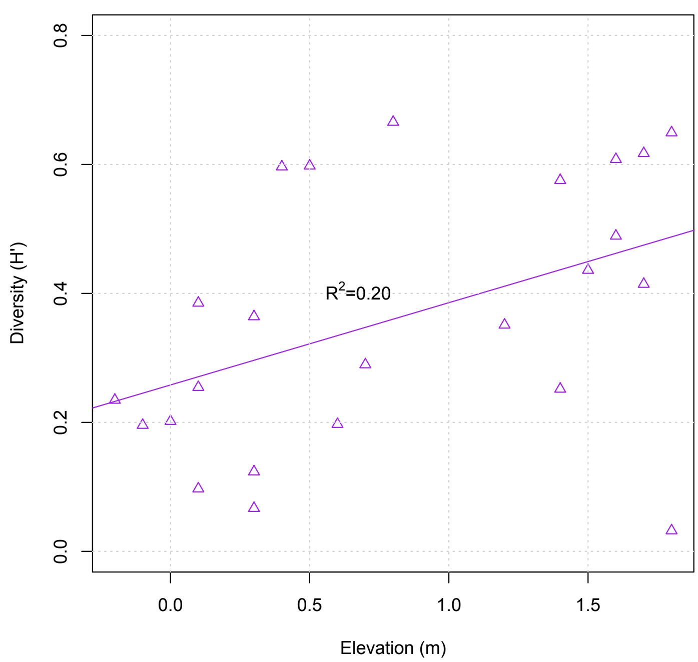

Figure 26. Brunswick Point species diversity, graphed by elevation.

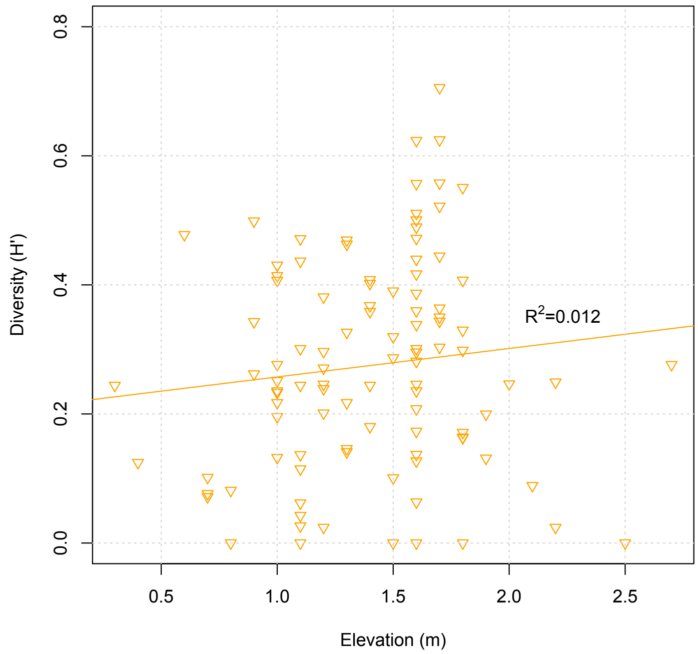

Figure 27. Boundary Bay species diversity, graphed by elevation.

3.1.4. Species Evenness

At all five marshes, there were insignificant relationships between evenness and elevation, and at each marsh, the ranges of evenness were approximately equal.

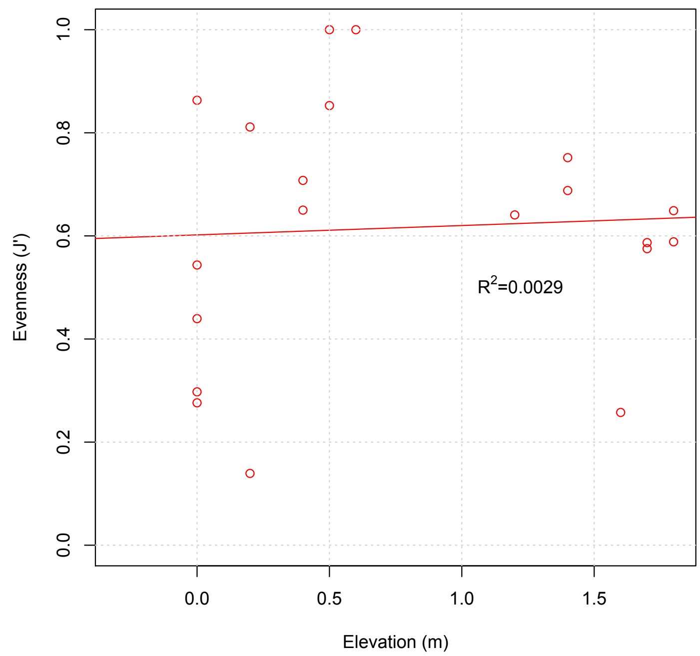

Figure 28. Sea Island species evenness, graphed by elevation.

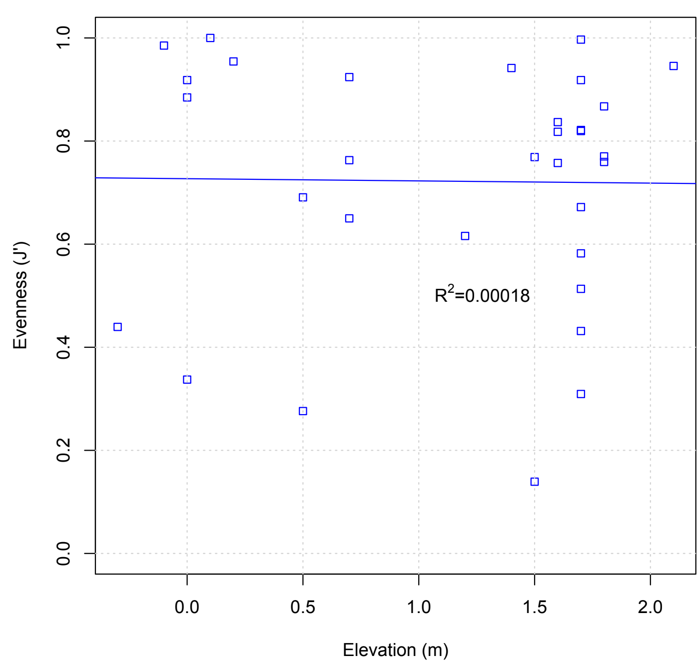

Figure 29. Lulu Island species evenness, graphed by elevation.

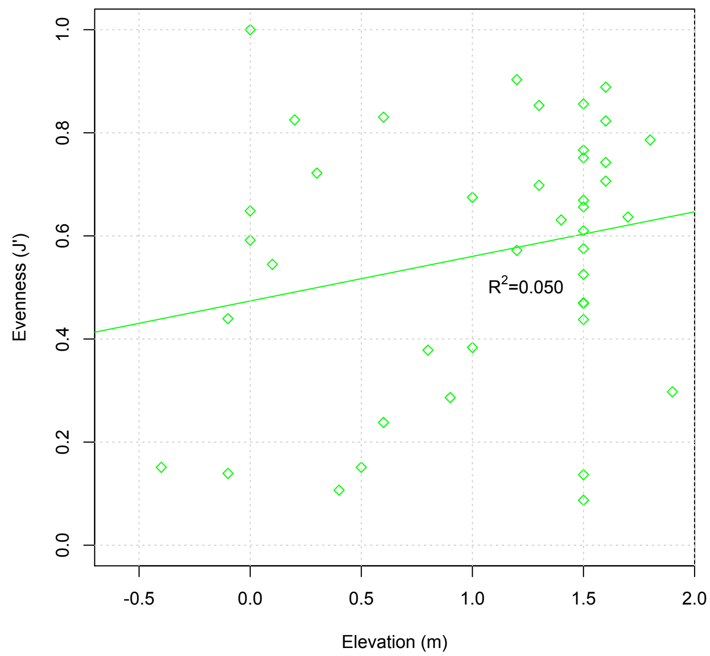

Figure 30. Westham Island species evenness, graphed by elevation.

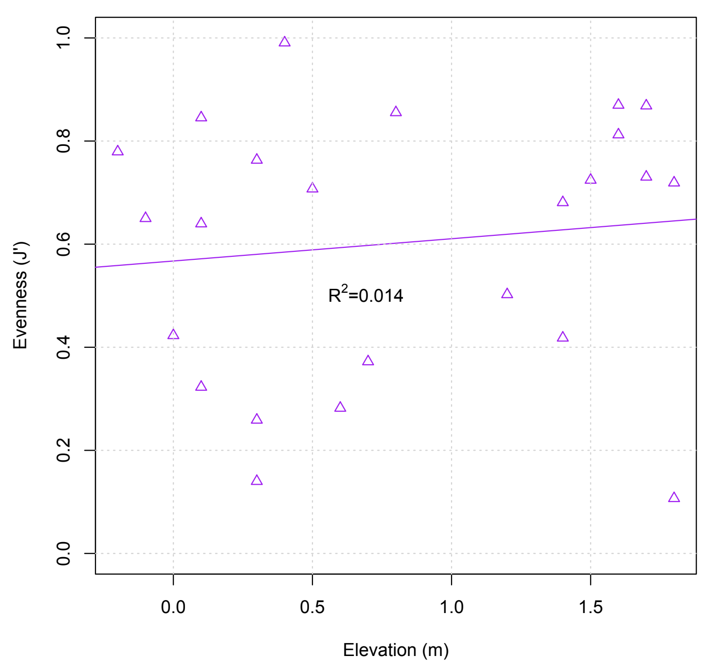

Figure 31. Brunswick Point species evenness, graphed by elevation.

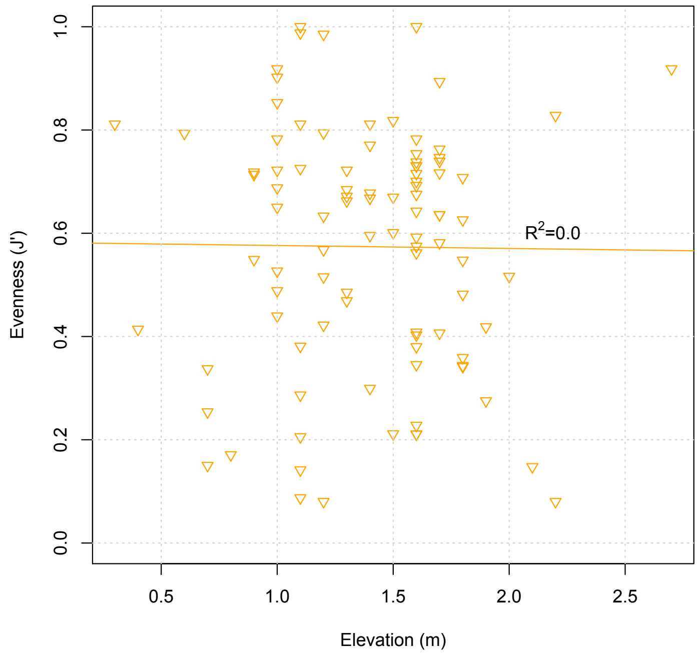

Figure 32. Boundary Bay species evenness, graphed by elevation.

3.1.5. Elevation Tolerance

The elevation, soil water, and soil pore water salinity tolerances of several key plant species at each marsh are shown in the next three sections. Each plant species is indicated by a four-letter code corresponding to the Latin name; these codes are found in Table 1.

Table 1. Species codes and corresponding Latin names of key plant species in the 2018 study at the Fraser River foreshore marshes

Species Code	Full Name
ATPA	*Atriplex plicata*
BOMA	*Bolboschoenus maritimus*
CALY	*Carex lyngbyei*
DISP	*Distichlis spicata*
GRST	*Grindelia stricta*
JUBA	*Juncus balticus*
POAN	*Potentilla anserina*
SAPA	*Sarcocornia pacifica*
SCPU	*Schoenoplectus pungens*
SCVA	*Schoenoplectus tabernaemontani*
SYSU	*Symphyotrichum subspicatum*
TRMA	*Trilochlin maritima*
TYLA	*Typha latifolia*
ZOJA	*Zostera japonica*

At Sea Island, there were six species of plants that were frequently observed in the marsh (Figure 33). Of these six species, *B. maritimus* and *S. pungens* have the largest elevation ranges. *P. anserina*, *D. spicata*, and *C. lyngbyei* all occupy the same approximate highest elevation zone of the marsh. *Z. japonica* is found at the lowest elevation, but its elevation range overlaps with that of *B. maritimus* and *S. pungens.* At Lulu Island, there were eight species of plants frequently observed (Figure 34). Three of the species, *P. anserina*, *T. latifolia*, and *D. spicata* occupied a narrow range of high elevation area. *C. lyngbyei* also occupied a narrow elevation range, with a few outliers. *S. tabernaemontani*, *B. maritimus*, and *S. pungens* occupied lower elevation areas with large ranges, with the latter two having the largest range. The elevation range of *Z. japonica* overlaps with that of *B. maritimus* and *S. pungens*. At Westham Island, there were seven species of plants frequently observed (Figure 35). *P. anserina*, *T. latifolia*, and *D. spicata* again occupied a narrow range of high elevation areas. *C. lyngbyei* was mostly found in the upper elevation areas of the marsh, and *S. tabernaemontani* was also in upper elevation areas. *B. maritimus* and *S. pungens* were found in the lower elevation areas with the largest range of elevation. There were four plant species observed in high number at Brunswick Point. *P. anserina, T. latifolia,* and *C. lyngbyei* occupied the higher elevation areas of the marsh, with *C. lyngbyei* having the largest range of the three. *S pungens* occupied a narrower, lower elevation area of the marsh. At Boundary Bay, the elevation range of each of the seven key species seen there was approximately equal, with *S. pacifica* having the largest elevation range.

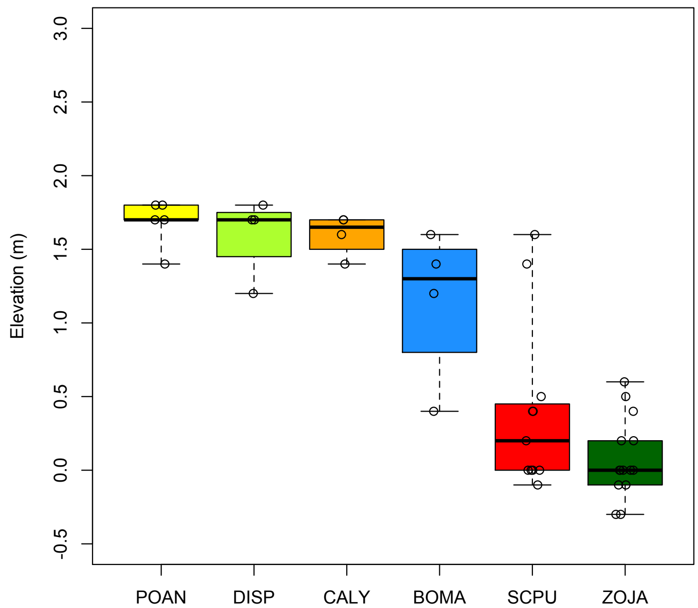

Figure 33. Elevation tolerance of six species of predominant plants at Sea Island.

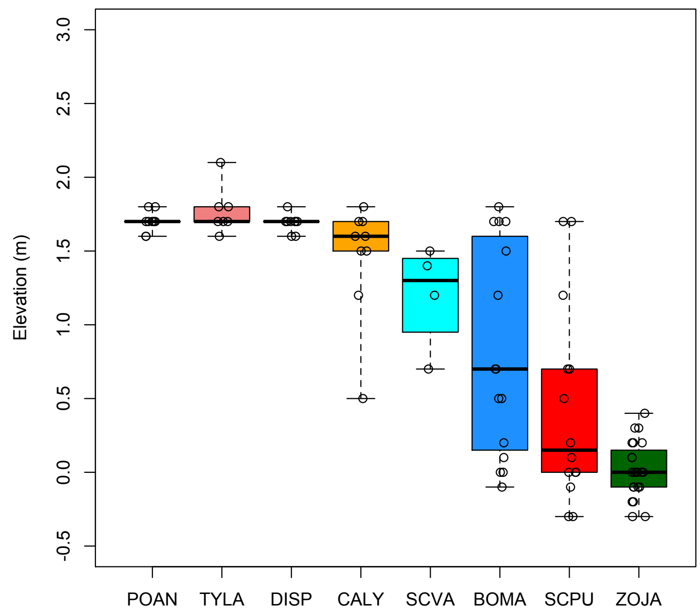

Figure 34. Elevation tolerance of eight species of predominant plants at Lulu Island.

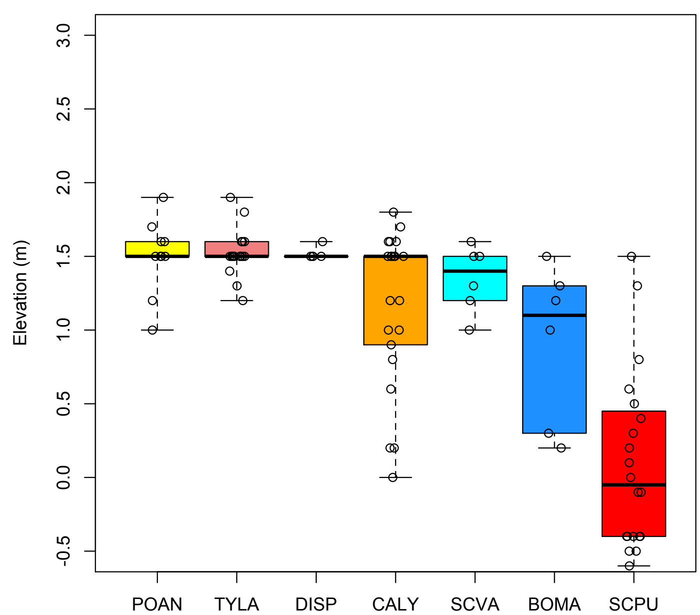

Figure 35. Elevation tolerance of seven species of predominant plants at Westham Island.

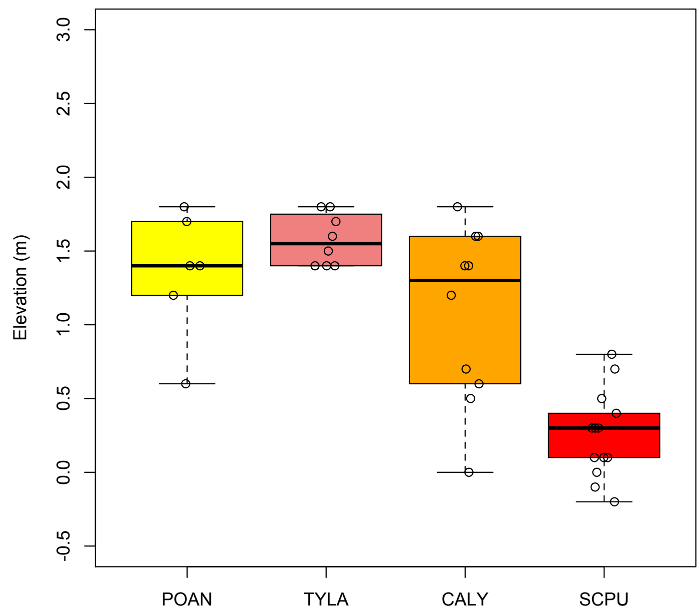

Figure 36. Elevation tolerance of four species of predominant plants at Brunswick Point.

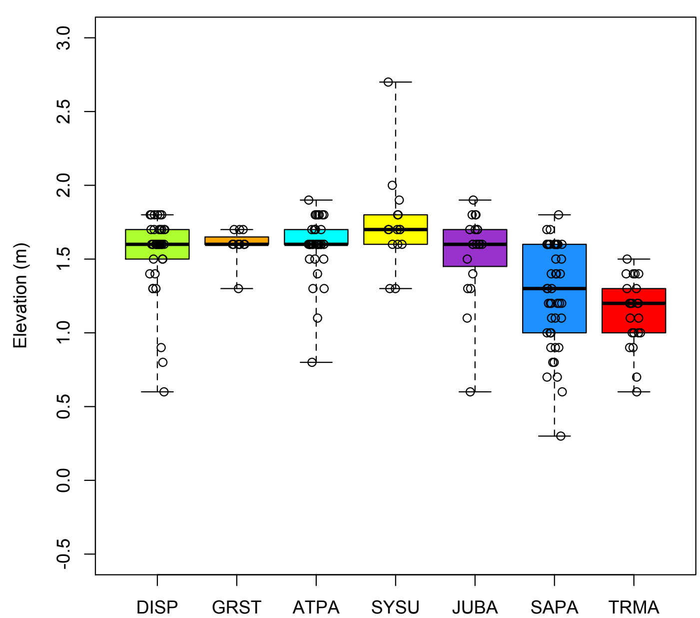

Figure 37. Elevation tolerance of seven species of predominant plants at Boundary Bay.

3.1.6. Soil Water Tolerance

The soil water at each of the five marshes varied. At Sea Island, *P. anserina*, *D. spicata*, and *C. lyngbyei* showed the largest range of soil water, while *B. maritimus, S. pungens,* and *Z. japonica* had a narrow range of soil water that was lower than the first three species (Figure 38). At Lulu Island, the eight species of key plants showed around the same soil water range, between 5 and 15 m^3/m^3 (Figure 39). At Westham Island, the soil water ranged between 5 and 15 m^3/m^3, with *P. anserina* and *D. spicata* having the largest soil water range (Figure 40). At Brunswick Point, the four plant species had low soil water ranges, between 2 and 10 m^3/m^3 (Figure 41). Boundary Bay showed the largest range of soil water range, from 0 to 35 m^3/m^3 (Figure 42). All seven of the plants had approximately the same range, with *J. balticus*, *S. pacifica*, and *T. maritima* having their soil water ranges more concentrated around the median value.

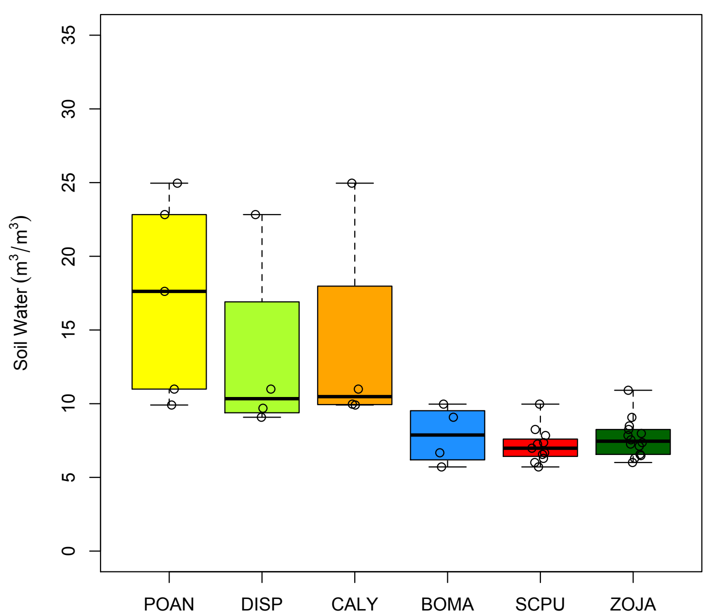

Figure 38. Soil water tolerance six species of predominant plants at Sea Island.

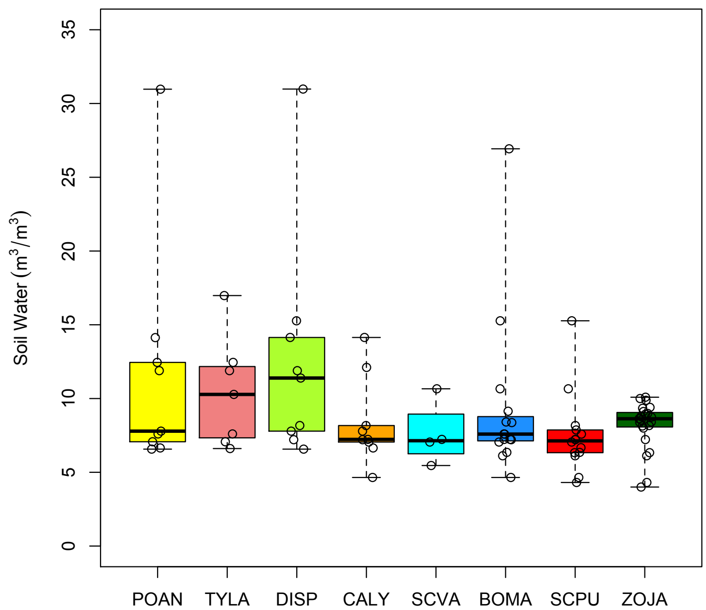

Figure 39. Soil water tolerance of eight species of predominant plants at Lulu Island.

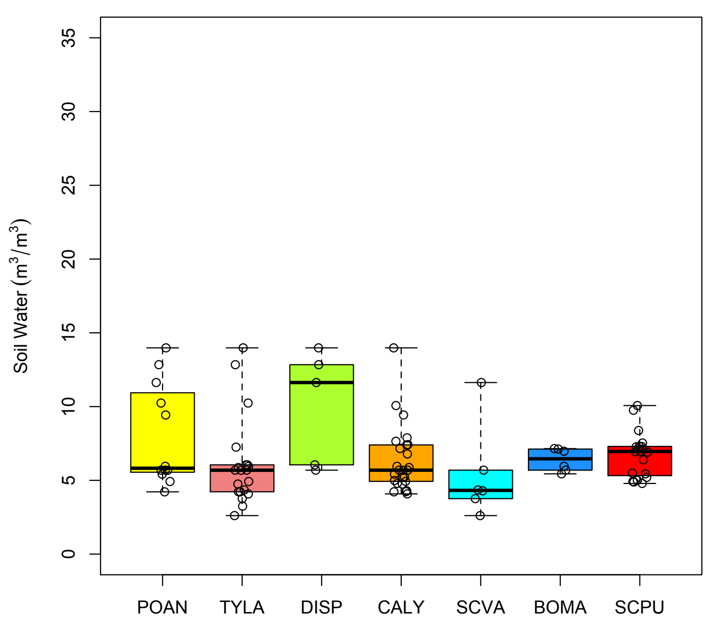

Figure 40. Soil water tolerance of seven species of predominant plants at Westham Island.

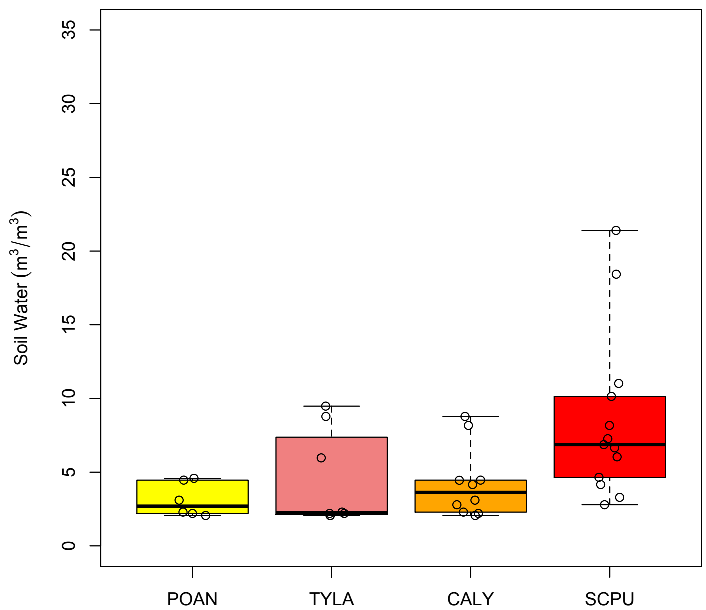

Figure 41. Soil water tolerance of four species of predominant plants at Brunswick Point.

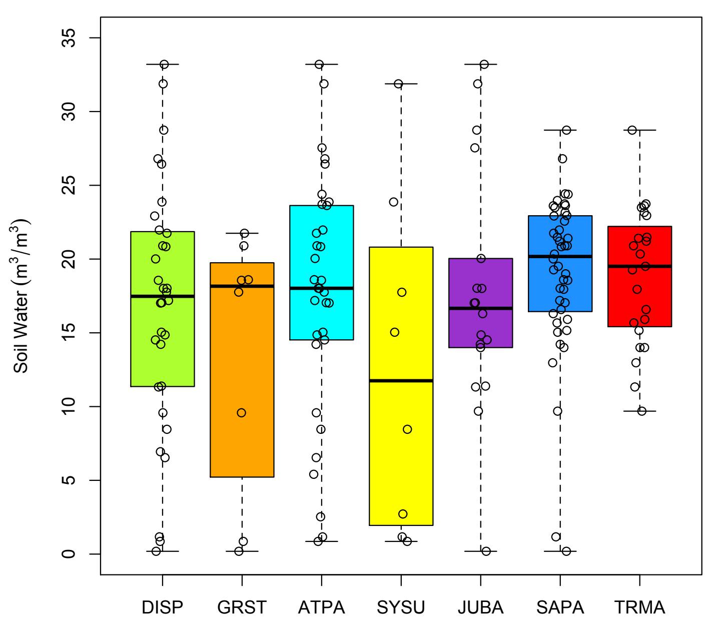

Figure 42. Soil water tolerance of seven species of predominant plants at Boundary Bay.

3.1.7. Soil Pore Water Salinity Tolerance

The soil pore water salinity varied over the five marshes greatly. At Sea Island, the six key plants were found in areas with salinity ranging from 15 - 30 ppt (Figure 43). At Lulu Island, the salinity ranged from 5 - 35 ppt (Figure 44). *B. maritimus*, *S. pungens*, and *Z. japonica* had the biggest range in soil pore water salinity, and also show the most tolerance to higher salinity levels. At Westham Island, the soil pore water salinity ranged from 0 - 20 ppt (Figure 45). *C. lyngbyei* showed the most range in soil pore water salinity, while *B. maritimus* and *S. pungens* showed the most tolerance to high soil pore water salinity levels. At Brunswick Point, the soil pore water salinity ranged from 2 -15 ppt, and the four key species each exhibited similar tolerance levels (Figure 46). At Boundary Bay, the soil pore water salinity was noticeably higher than the other four marshes, ranging from 8 – 55 ppt (Figure 47). Each plant species had a median soil pore water salinity between 30 and 40 ppt, and *G. stricta*, *S. subspicatum*, and *J. balticus* had the narrowest range around the median value.

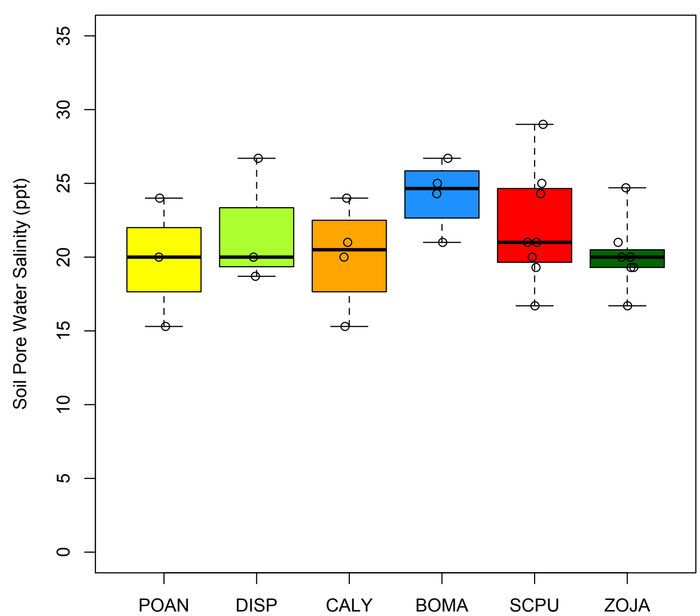

Figure 43. Soil pore water salinity tolerance of six species of predominant plants at Sea Island.

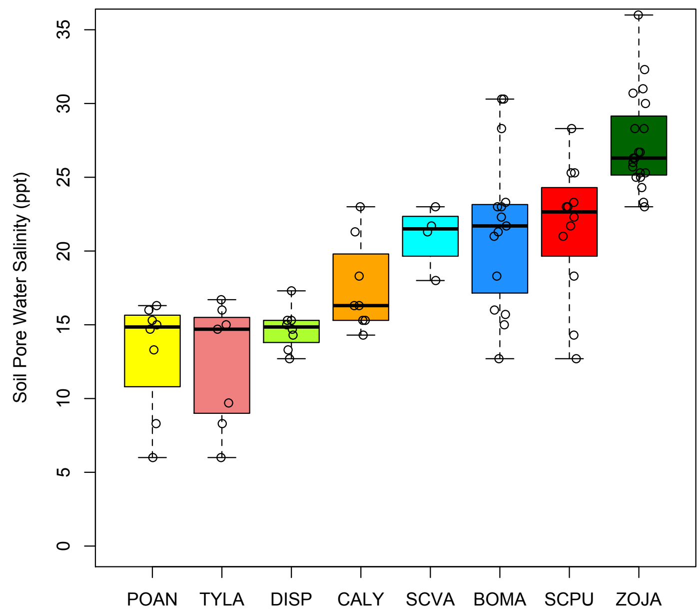

Figure 44. Soil pore water salinity tolerance of eight species of predominant plants at Lulu Island.

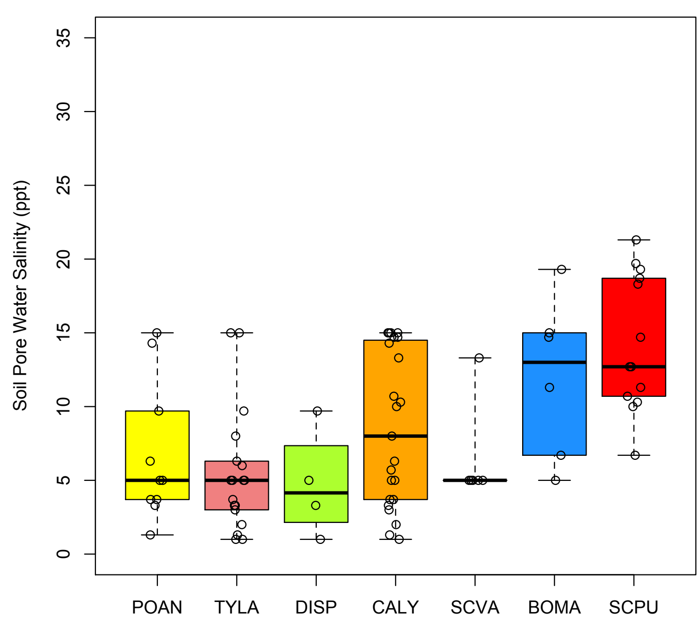

Figure 45. Soil pore water salinity tolerance of seven species of predominant plants at Westham Island.

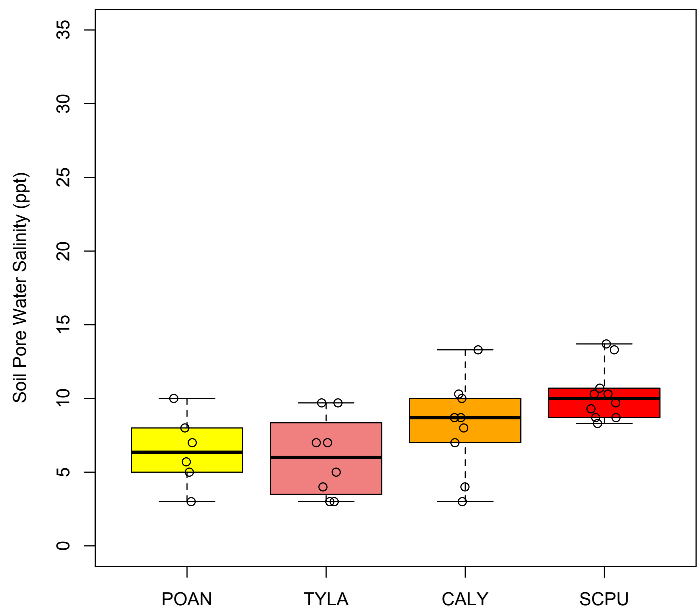

Figure 46. Soil pore water salinity tolerance of four species of predominant plants at Brunswick Point.

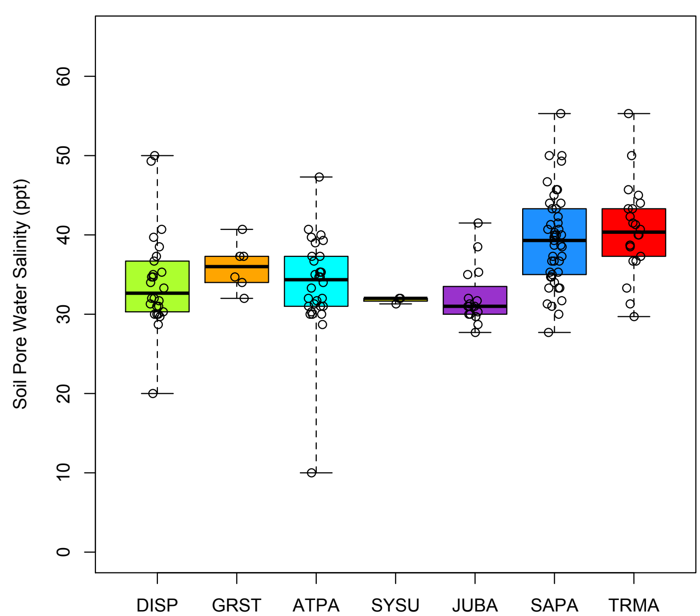

Figure 47. Soil pore water salinity tolerance of seven species of predominant plants at Boundary Bay.

The results shown in the previous three sections illustrate the wide range that each key species may experience and grow in at each of the marshes. Certain species have narrow ranges in certain soil parameters, like *B. maritimus* and *S. pungens* with soil water at most of the marshes, while having wide ranges over elevation and soil pore water salinity.

3.2. Predominant Plant Densities and Heights

3.2.1. Schoenoplectus pungens

S. pungens was generally predominant in lower elevation areas of the four marshes that it was found in (Figure 48). The density of *S. pungens* generally increased as the elevation decreased, with the highest correlation at Lulu Island (R^2 of 0.50; weak relationship) and Sea Island (R^2 of 0.30; weak relationship). The average height of *S. pungens* showed no distinct relationship with regard to elevation across the four marshes. At Sea Island, the average height decreased with distance from the dike (R^2 of 0.48, weak relationship), and at Lulu Island, Brunswick Point, and Westham Island, the R^2 values indicated an insignificant relationship.

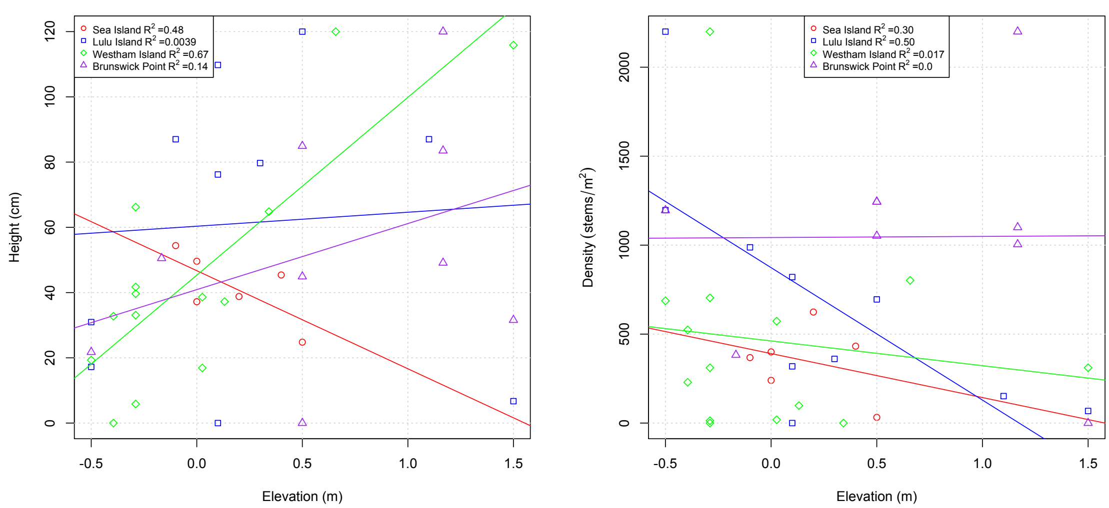

Figure 48. *Schoenoplectus pungens* height (left) and density (right) for Westham Island, Lulu Island, Sea Island, and Brunswick Point, graphed by elevation.

3.2.2. Bolboschoenus maritimus

B. maritimus was observed as Westham Island, Lulu Island, Sea Island, and Brunswick Point (Figure 49). It was observed in several plots and elevations at Westham Island and Lulu Island. The R^2 values at both Lulu Island and Westham Island for height and density of *B. maritimus* indicate an insignificant relationship.

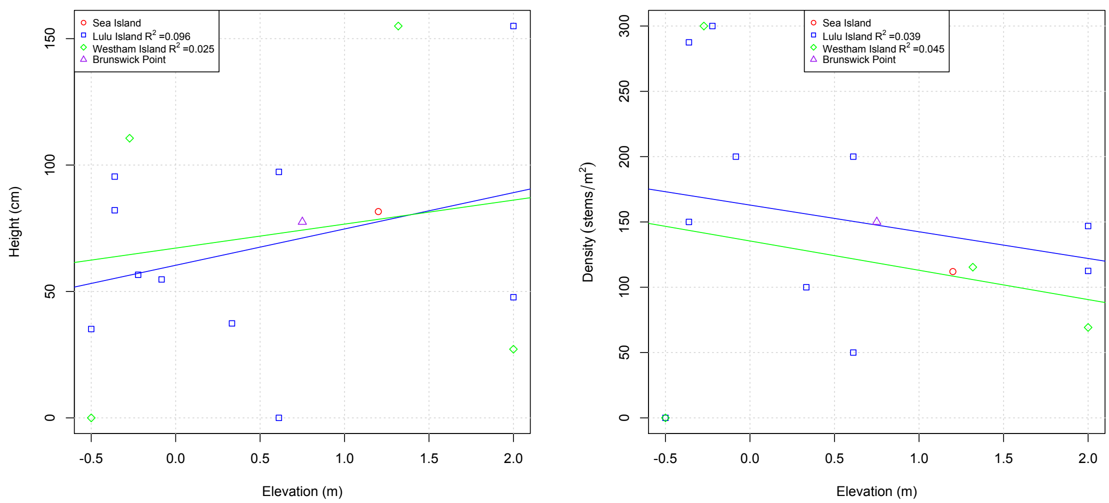

Figure 49. *Bolboschoenus maritimus* height (left) and density (right) for Westham Island, Lulu Island, Sea Island, and Brunswick Point, graphed by elevation.

3.2.3. Carex lyngbyei

C. lyngbyei was observed at four marshes (Figure 50). The average height increased with increasing elevation at Westham Island (R^2 of 0.41; weak relationship), Sea Island (R^2 of 0.97; strong relationship), and Brunswick Point (R^2 of 0.47; weak relationship). At Lulu Island the height decreased with increasing elevation (R^2 of 0.27; weak relationship). At all four marshes, the density of *C. lyngbyei* increased with distance seaward from the dike, with the highest correlation found at Sea Island (R^2 of 0.78; strong relationship), Lulu Island (R^2 of 0.78; strong relationship), and Brunswick Point (R^2 of 0.53; medium relationship).

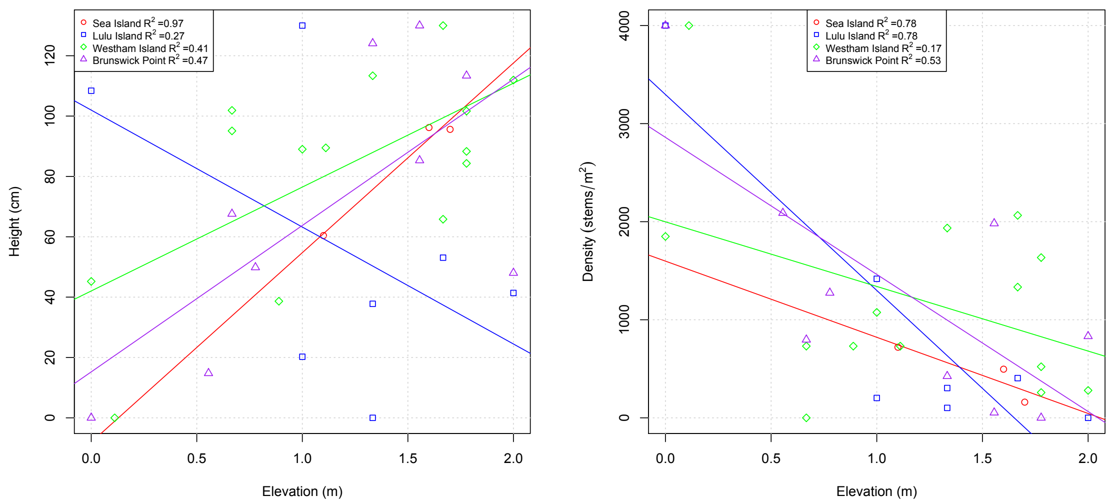

Figure 50. *Carex lyngbyei* height (left) and density (right) for Westham Island, Lulu Island, Sea Island, and Brunswick Point, graphed by elevation.

3.2.4. Schoenoplectus tabernaemontani

S. tabernaemontani was observed at several elevations at Westham Island and Lulu Island, and at Brunswick Point it was only observed at one elevation (Figure 51). At Westham Island, the height decreased with increasing elevation (R^2 of 0.77; strong relationship), and at Lulu Island, height increased with increasing elevation (R^2 of 0.28; weak relationship). At both Westham Island and Lulu Island, the density increased with increasing elevation, with Westham Island having a medium relationship (R^2 of 0.66), and Lulu Island having a strong relationship (R^2 of 0.88).

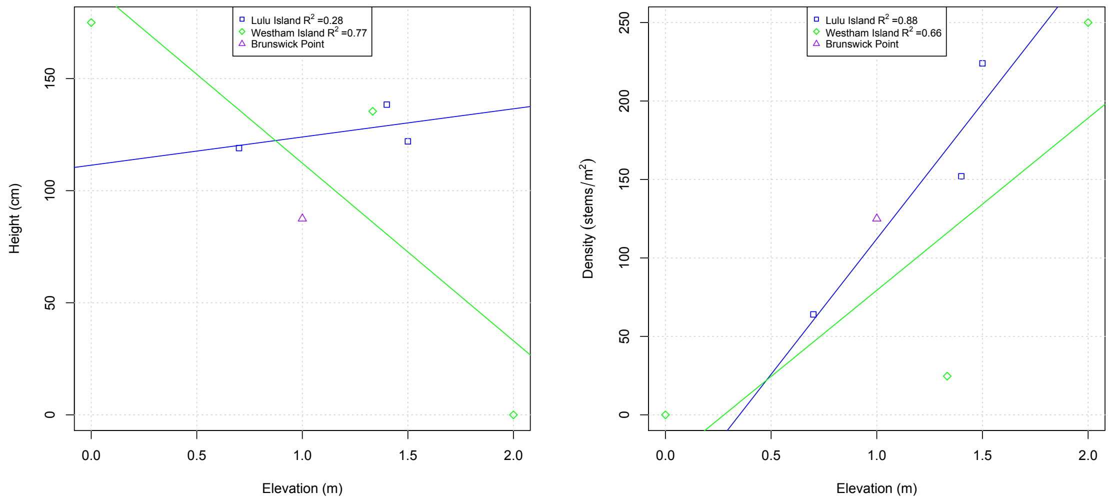

Figure 51. *Schoenoplectus tabernaemontani* height (left) and density (right) for Westham Island, Lulu Island, and Brunswick Point, graphed by elevation.

3.2.5. Distichlis spicata

D. spicata was observed at Westham Island, Lulu Island, Sea Island, and Boundary Bay (Figure 52). It was only observed at more than one elevation at Boundary Bay. At Boundary Bay, both height and density showed insignificant relationships to elevation.

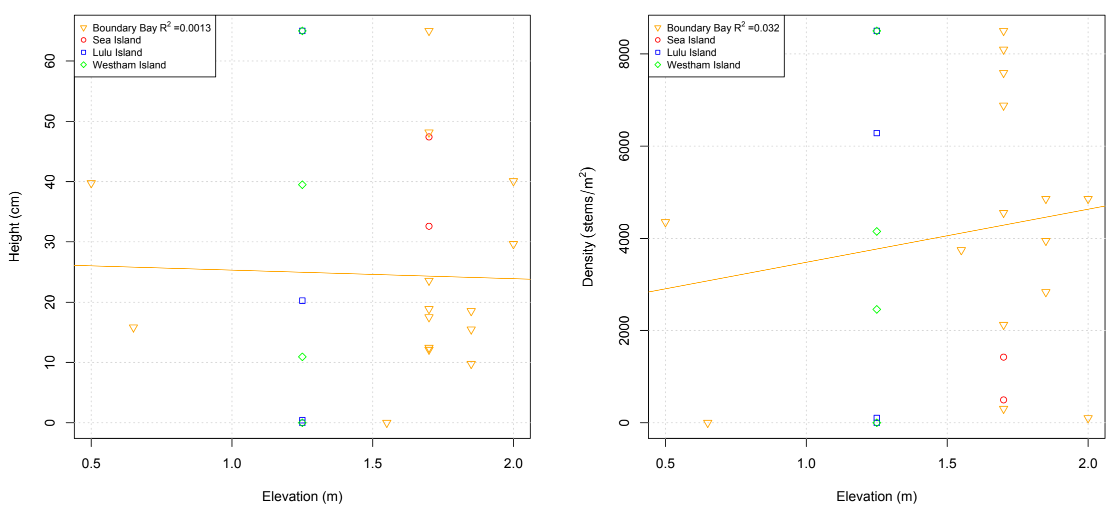

Figure 52. *Distichlis spicata* height (left) and density (right) for Westham Island, Lulu Island, Sea Island, and Boundary Bay, graphed by elevation.

3.2.6. *Juncus balticus*

J. balticus was only found in the plots at Boundary Bay. Both height and density showed an insignificant relationship to elevation (Figure 53).

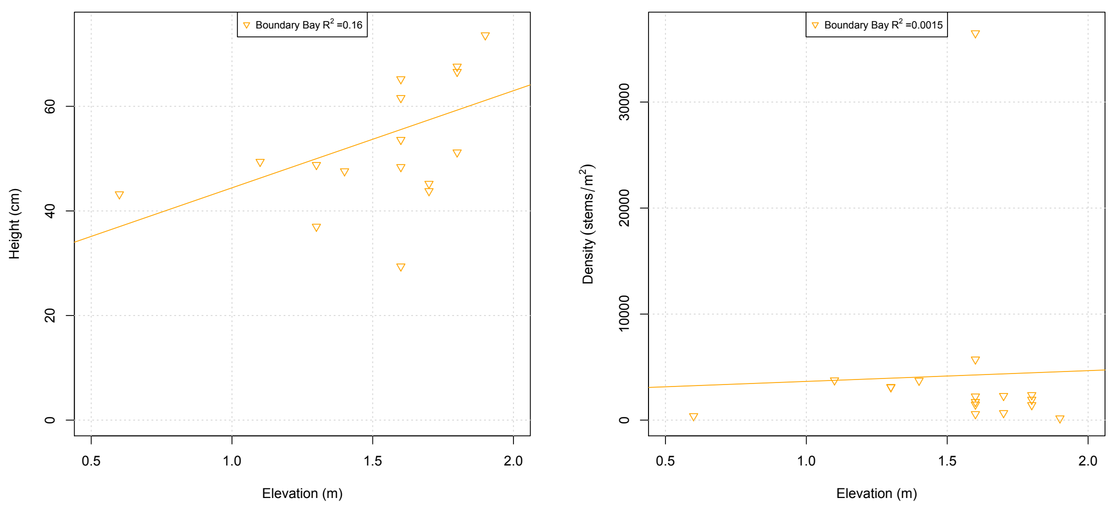

Figure 53. *Juncus balticus* height (left) and density (right) at Boundary Bay, graphed by elevation.

3.2.7. *Zostera japonica*

Z. japonica was observed as a predominant plant at Lulu Island and Sea Island. It was generally found at the lowest elevations, beyond upright vegetation. At Sea Island and Lulu Island, there was an insignificant relationship between height and elevation (Figure 54). There was an insignificant relationship between density and height at both marsh locations.

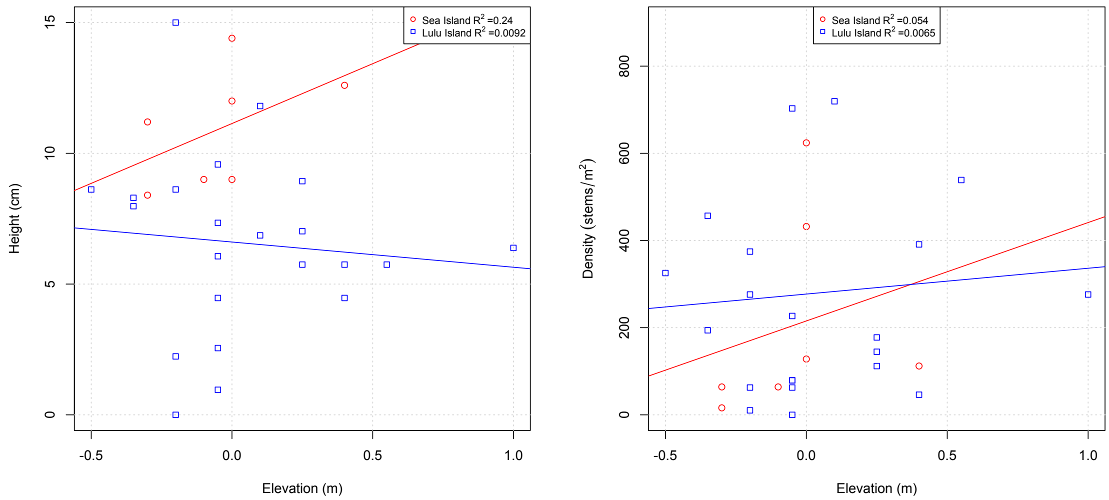

Figure 54. *Zostera japonica* height (left) and density (right) at Lulu Island and Sea Island, graphed by elevation.

3.2.8. Sarcocornia pacifica

S. pacifica was observed in the plots at Boundary Bay. The height increased with increasing elevation, but this was an insignificant relationship (R^2 of 0.059) (Figure 55). The density decreased with increasing elevation, but this was an insignificant relationship (R^2 of 0.10).

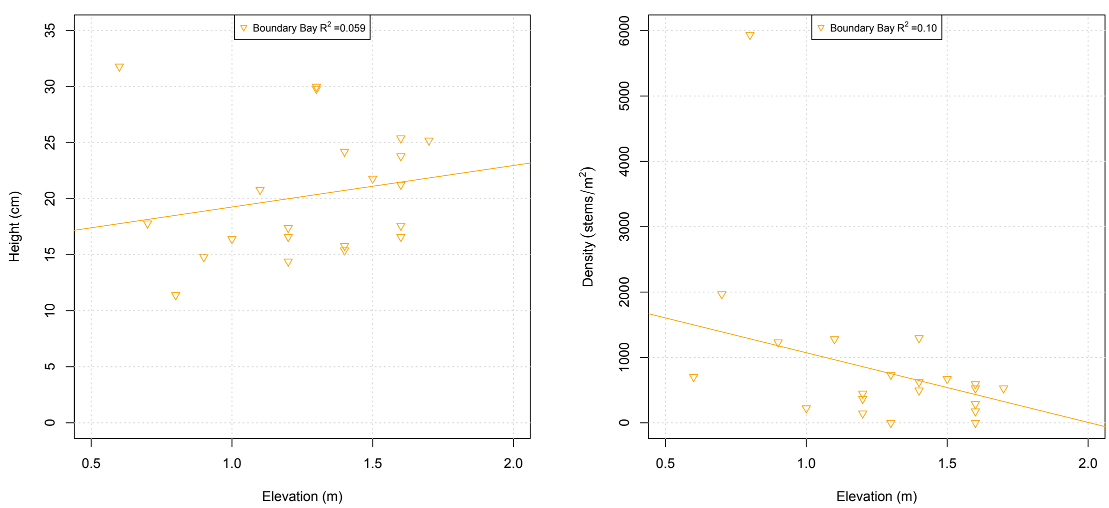

Figure 55. *Sarcocornia pacifica* height (left) and density (right) at Boundary Bay, graphed by elevation.

3.2.9. Triglochin maritima

T. maritima was observed at as a predominant plant at Boundary Bay. The height increased with increasing elevation, with a medium strength relationship (R^2 of 0.61). The density decreased with increasing elevation, with a weak relationship (R^2 of 0.33).

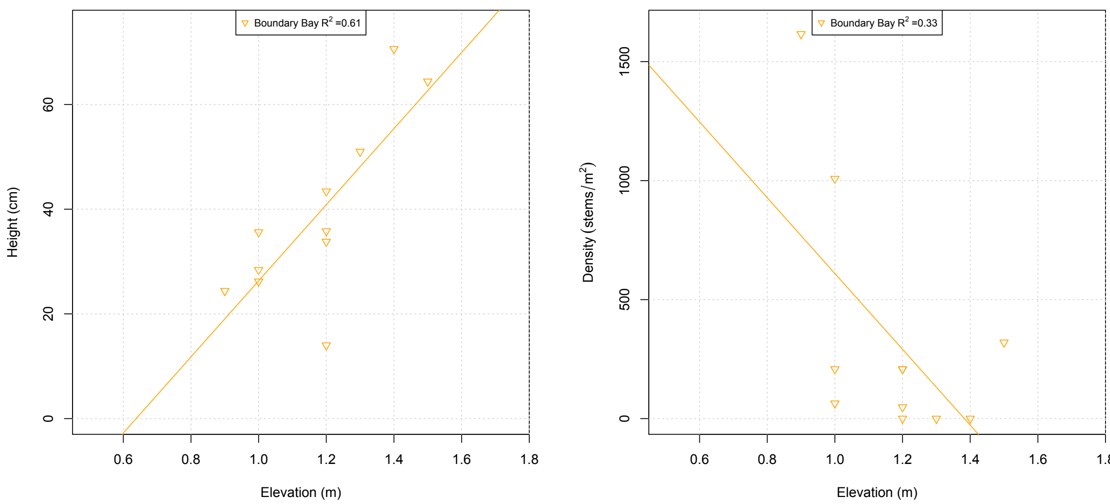

Figure 56. *Triglochin maritima* height (left) and density (right) at Boundary Bay, graphed by elevation.

3.3. Lulu Island Comparisons to Historical Studies

3.3.1. Plant Height

A t-test was conducted to determine if there were statistically significant differences between the heights of *S. pungens* and *B. maritimus* in 1981 and 2018. The 1981 data was collected by Boyd (1983). The null hypotheses were that there would be no difference in height between 1981 and 2018 in each of the plant species, and the alternative hypotheses were that there would be a difference in height in either or both of the species between 1981 and 2018 (Table 2). The mean height of *S. pungens* was 75.0 cm in 1981, and 57.5 cm in 2018 mean height of *B. maritimus* was 89.7 cm in 1981, and 110 cm in 2018 (Table 3). The distributions of the data of each of the four datasets are shown, with several outliers in the *S. pungens* 1981 and *B. maritimus* 2018 datasets (Figure 57).

Table 2. Null and Alternative Hypotheses for *S. pungens* and *B. maritimus* in 1981 and 2018 at Lulu Island.

S. pungens	*B. maritimus*
H_0: $\mu_{pungens2018} = \mu_{pungens1981}$	H_0: $\mu_{maritimus2018} = \mu_{maritiimus1981}$
H_A: $\mu_{pungens2018} \neq \mu_{pungens1981}$	H_A: $\mu_{maritimus2018} \neq \mu_{maritimus1981}$

Table 3. Descriptive statistics of *S. pungens* and *B. maritimus* heights in 1981 and 2018 at Lulu Island.

	Mean (cm)	Standard Deviation	Standard Error	Sample Size
S. pungens 2018	57.5	30.7	4.34	50
S. pungens 1981	75.0	14.8	1.10	180
B. maritimus 2018	110	27.6	3.90	50
B. maritimus 1981	89.7	23.3	3.29	50

Since the p-value is less than the alpha value for *S. pungens*, the null hypothesis is rejected (Table 4). The heights of *S. pungens* are significantly higher in 1981 than in 2018. Since the p-value is less than the alpha value of *B. maritimus* the null hypothesis is rejected. The height of *B. maritimus* is significantly taller in 2018 than in 1981.

Table 4. T-test results of *S. pungens* and *B. maritimus* heights from 1981 and 2018 at Lulu Island.

Parameter	Result *S. pungens*	Result *B. maritimus*
T-critical	1.97	1.98
Degrees of Freedom	229	98
T-statistic	-5.66	4.42
P-Value	4.52×10^{-8}	8.70×10^{-5}

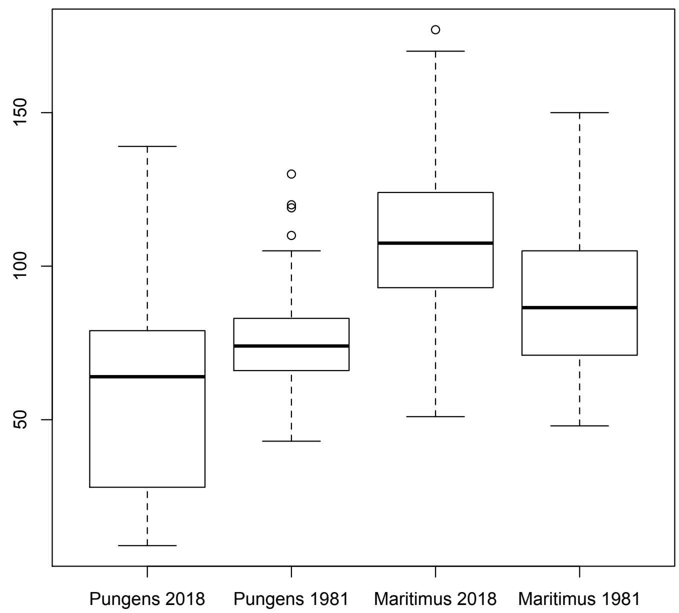

Figure 57. Distribution of *S. pungens* and *B. maritimus* heights from 1981 and 2018.

3.3.2. Plant Density

Stem density measurements of *S. pungens* have been conducted in 1989 and 2011 at Lulu Island, Westham Island and Brunswick Point (Boyd et al., 2011, unpublished data). This data collection was done at much closer intervals than my surveys, so only general comparisons can be made. The quadrat size in both surveys was 0.25 x 0.25 m. It was noted that between 1989 and 2011, the overall stem densities declined by 40% (Boyd et al., 2011, unpublished data). My stem densities are approximately in line with what was found in 2011, with my stem densities ranging from 2 – 53 stems/quadrat at Lulu Island, 25 - 39 stems/quadrat at Sea Island, 3 – 29 stems/quadrat at Brunswick Point, and 1 – 136 stems/quadrat at Westham Island. It is impossible to say if the marshes have had a noticeable change in *S. pungens* stem density since 2011.

3.3.3. Plant Dominance

Percent dominance is a measure that was used historically to estimate the presence of some of the key plants at Lulu Island. The 1981 data was collected by Boyd (1983). My data was corrected to reflect the same measurement. Percent dominance is a cover measurement that does not take into consideration bare ground. Figure 58 shows the dominance of *S. pungens* in 1981 and 2018. The dominance of *S. pungens* was higher in 1981 than in 2018, especially in the areas further from the dike.

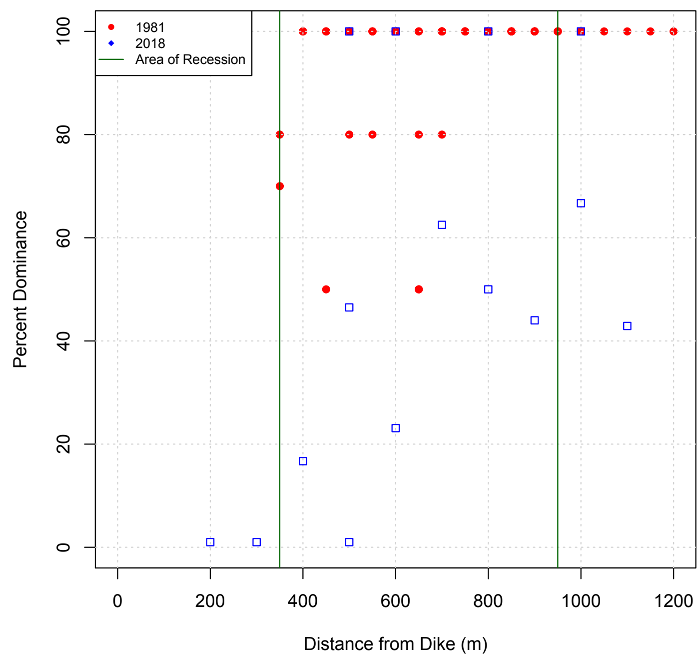

Figure 58. Comparison of percent dominance of *S. pungens* from 1981 and 2018. The 6 transects were plotted by distance from the dike, to match up with historical data.

B. maritimus is a key marsh species at Lulu Island, present both in 1981 and 2018. Figure 59 shows the change in percent dominance from 1981 to 2018. The percent dominance is variable in both time periods, and does not show a noticeable difference in the area where the marsh has receded.

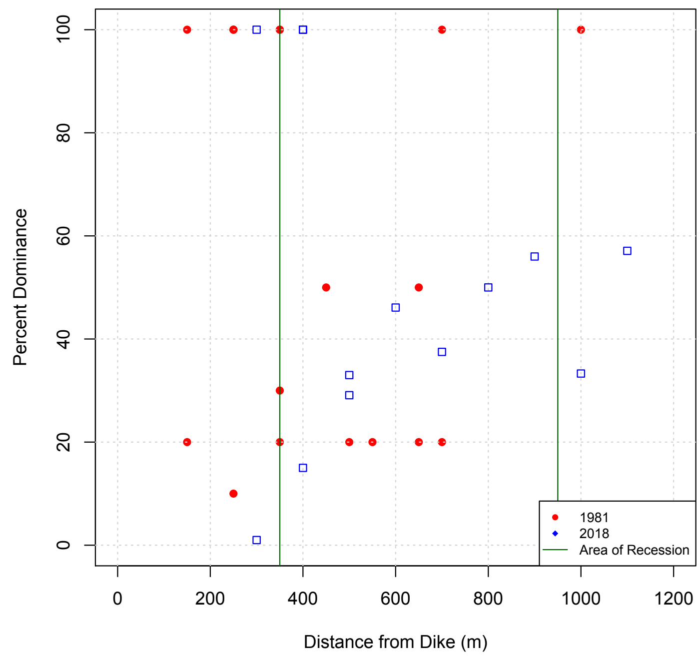

Figure 59. Comparison of percent dominance of *B. maritimus* from 1981 and 2018. The 6 transects were plotted by distance from the dike, to match up with historical data.

The percent dominance of the 2018 results were matched up with the 1981 results from Boyd (1983). Each transect is compared side by side in Figures 60, 61, 62, 63, 64, and 65, and Lulu Island 1 is the furthest north transect on the island, and Lulu Island 6 is the furthest south. The historical marsh edge and current marsh edge are both delineated on the maps. It is important to note that in 2018, the quadrats were done every 100 m along each transect, whereas in 1981, they were done every 100 m until the zone of *B. maritimus* was reached, then quadrats were done every 50 m. At Lulu Island 1, there are several places in lower elevation areas where there was *S. pungens* historically, where it wasn't observed in 2018. The higher elevation areas look similar to 1981 areas. At Lulu 2, there is pronounced marsh recession. There are many areas where *S. pungens* and *B. maritimus* were present in 1981, where they were not present in 2018. The upper elevation areas of the marsh have similar plant species in 2018 and 1981. At Lulu Island 3, the *S. pungens* and *B. maritimus* that was present in 1981 is missing in 2018. In 1981, the *B. maritimus* was present more in the high marsh areas, whereas in 2018, the high marsh contained *C. lyngbyei*, grass, and *T. latifolia*. At Lulu Island 4, again, the *S.*

pungens and *B. maritimus* that was present historically is no longer present in 2018. The upper marsh of Lulu Island 4 contains similar species in 1981 and 2018. At Lulu Island 5, the *S. pungens* and *B. maritimus* that was present historically is no longer present in 2018. The upper marsh of Lulu Island 5 contains similar species in 1981 and 2018. Lulu Island 6 has not experienced the same level of large scale recession as the other transects at Lulu Island. The side by side comparison of these two transects shows more *B. maritimus* in 2018, and less *T. maritima* in 2018. The *S. pungens* was found closer to the dike in 1981.

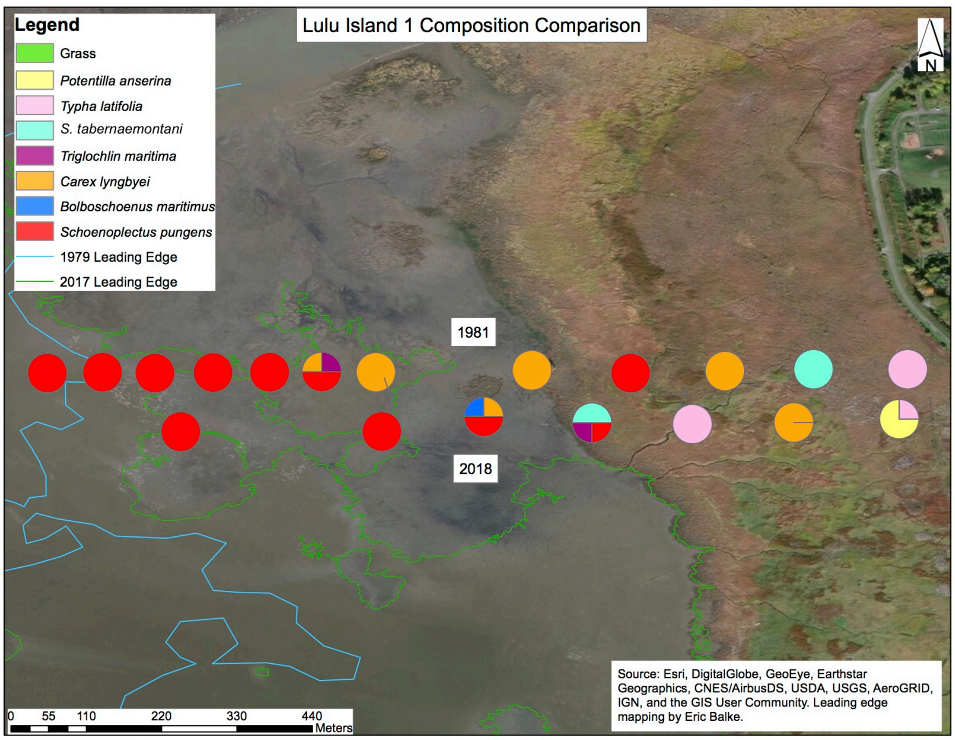

Figure 60. Lulu Island 1 transect composition comparison of 1981 and 2018 data.

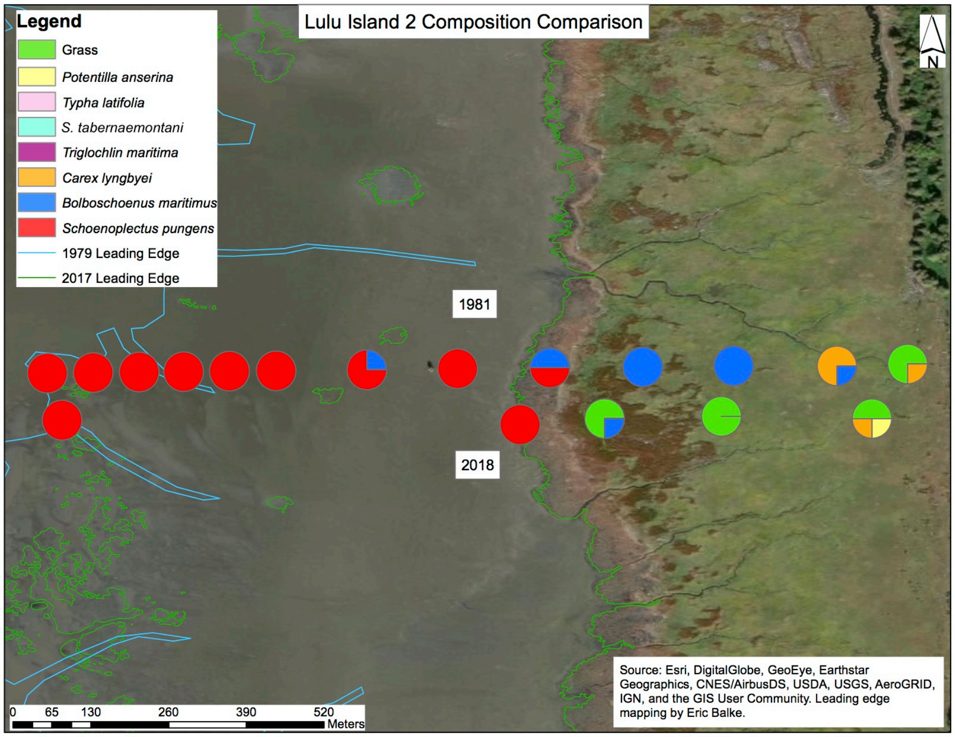

Figure 61. Lulu Island 2 transect composition comparison of 1981 and 2018 data.

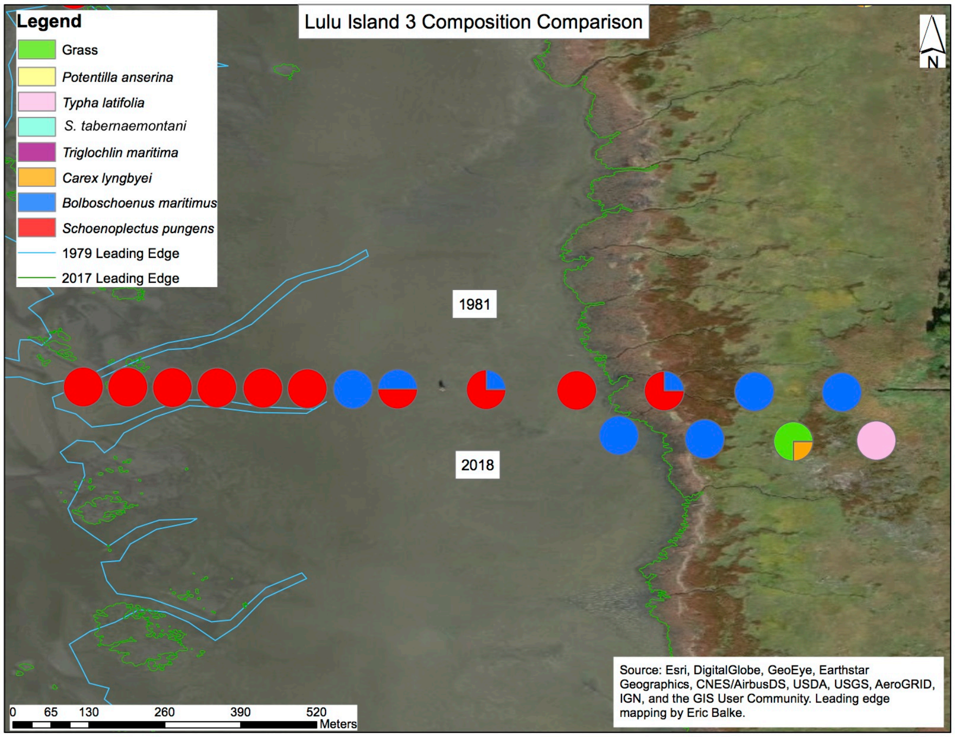

Figure 62. Lulu Island 3 transect composition comparison of 1981 and 2018 data.

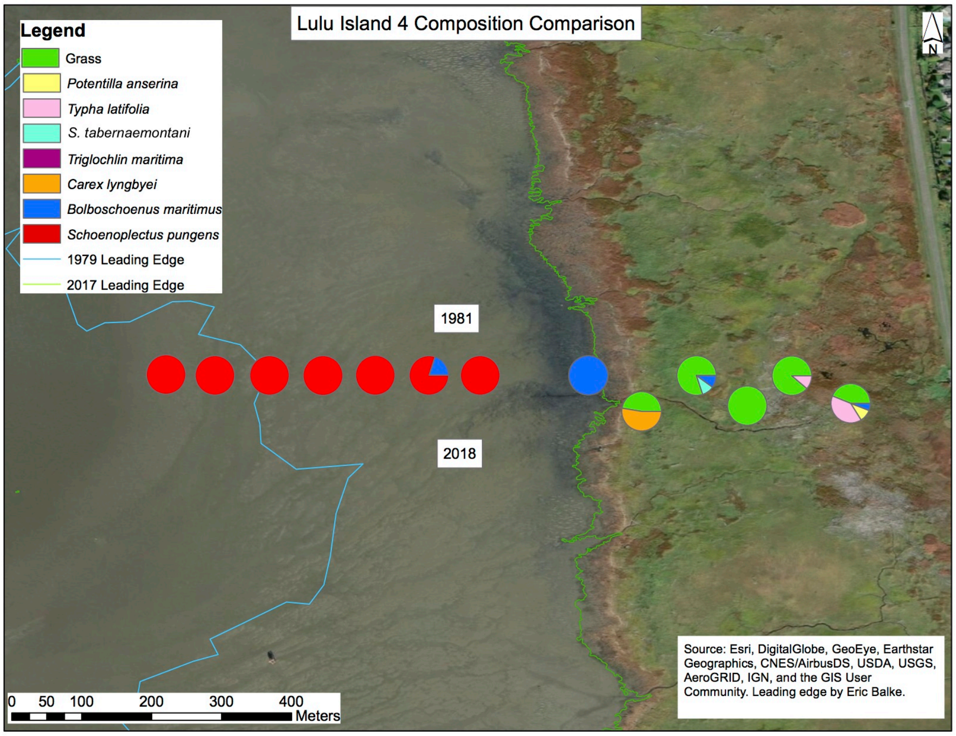

Figure 63. Lulu Island 4 transect composition comparison of 1981 and 2018 data.

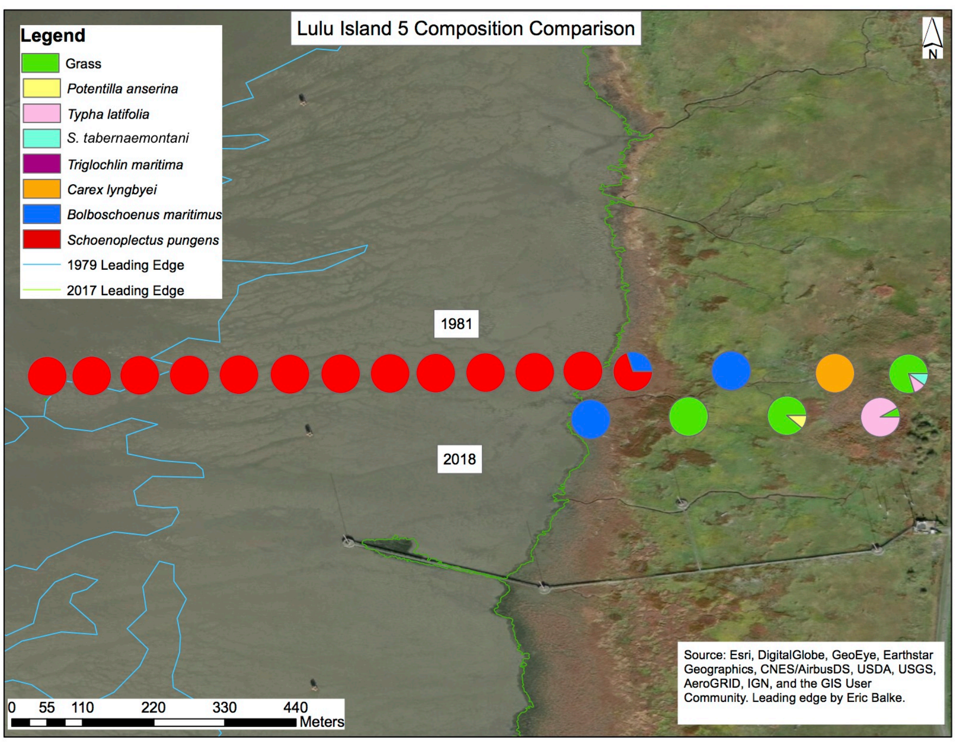

Figure 64. Lulu Island 5 transect composition comparison of 1981 and 2018 data.

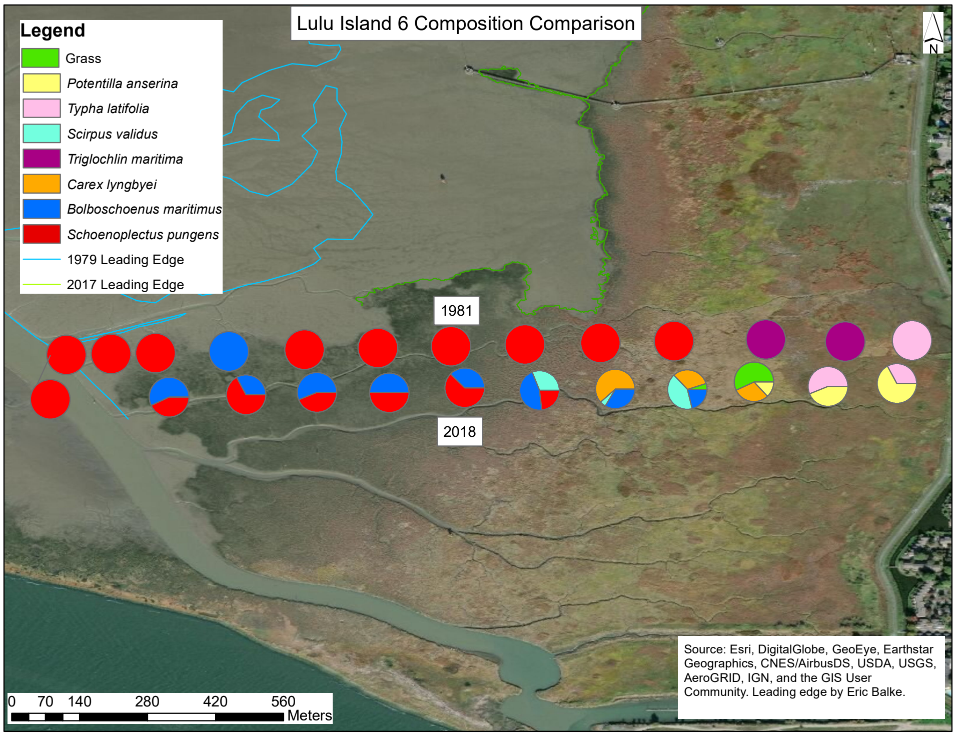

Figure 65. Lulu Island 6 transect composition comparison of 1981 and 2018 data.

3.4. Yamanaka (1975) Comparison

The comparison between Yamanaka (1975) and my data is challenging, as the raw data is not available. Yamanaka put his stem density data into four categories, based on how many stems were present per m^2. I put my stem densities in the same categories as he did, and have compared them side by side in Figure 66. I also only took the data from my transects that most closely matched up with his. The most noticeable differences in density are between *S. tabernaemontani*, with the density higher in 2018 than 1973/74, and *T. maritima*, with the density higher in 2018 than in 1973/74. I also graphed Yamanaka's soil conductivity measurements from his relevant transects. The brackish marshes that Yamanaka (1975) measured show a negative relationship between elevation and conductivity (Figure 67). Two of transects that Yamanaka (1975) did at Boundary Bay show a positive relationship between distance from the dike and conductivity, and one transect shows a negative relationship between distance from the dike and conductivity (Figure 68). The primary purpose of these graphs is for trend comparison to my soil salinity data.

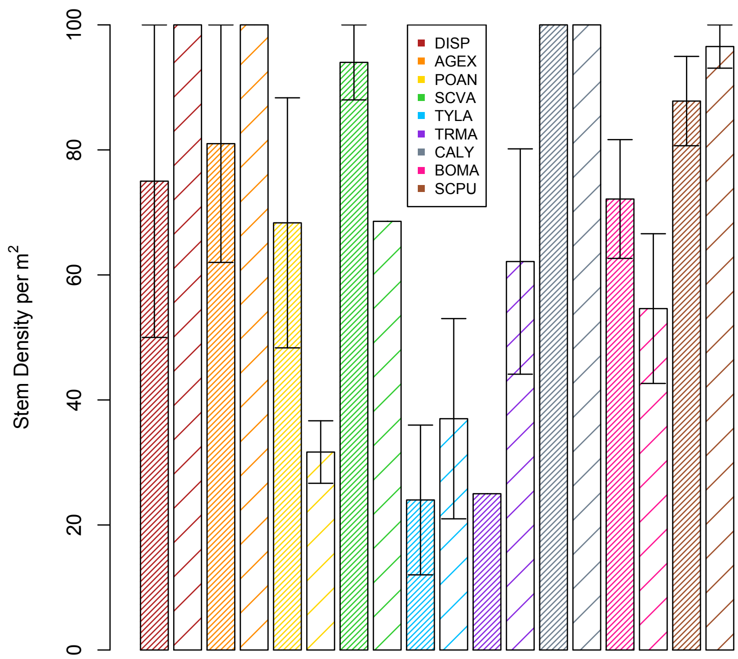

Figure 66. Density comparison of key plants in 2018 and 1973/74. Each plant species' density is shown in the same colour, with the high density stripes on the left representing the 2018 density data, and the low density striped on the right representing the 1973/74 data. The mean data point is shown, ± standard error. If a bar does not have an error bar, it means that either all the stem densities were the same, or there was only one data point.

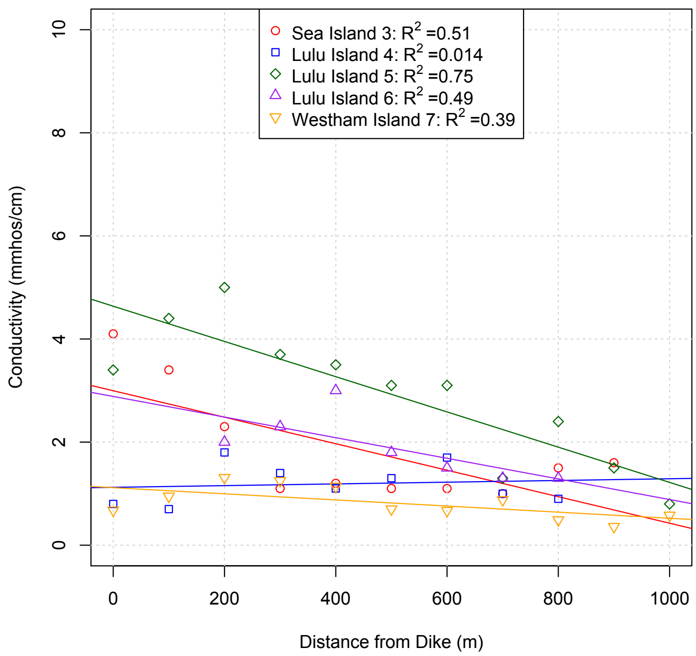

Figure 67. Yamanaka (1975) soil conductivity measurements graphed by distance from dike at Sea Island, Lulu Island, and Westham Island.

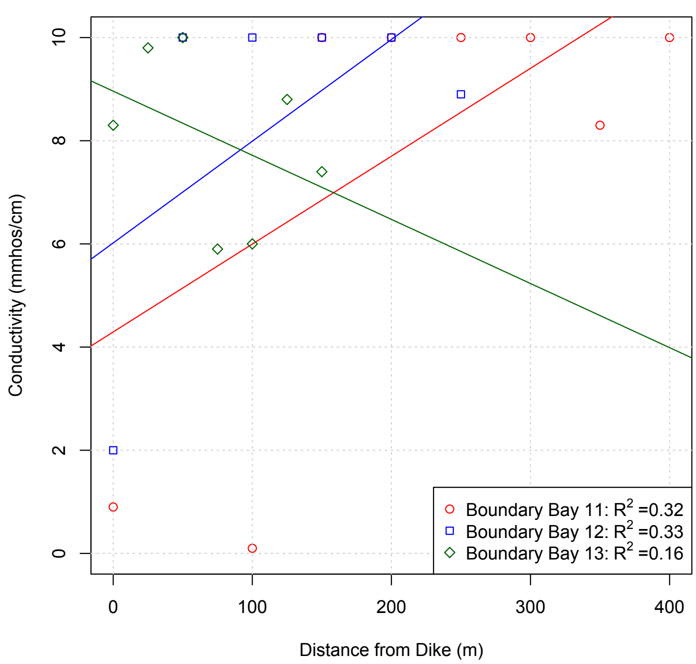

Figure 68. Yamanaka (1975) soil conductivity measurements graphed by distance from dike at Boundary Bay.

Chapter 4. Discussion

4.1. Soil Water

Soil water is affected by the time since inundation and the particle size present in the soil. Larger particle sizes allow water to drain faster in periods between inundation (Hutchison, 1982). In my study, it was difficult to control precisely for time since inundation. However, when I did my transect surveys, I started one transect approximately 2 hours before low tide, and made my way out to the lowest elevation part of the transect, then walked over to the second transect and started at the lowest elevation spot. This allowed me to do my soil measurements at approximately the same time since inundation at each plot along the transects. Four of the marshes had an insignificant relationship between soil water and elevation: Lulu Island, Westham Island, Brunswick Point, and Boundary Bay. I believe that this is a reflection of the variability of particle sizes that are found across each marsh (Leuternauer and Finn, 1982). At Boundary Bay, the soil water had a higher range than at the other four marshes. This was surprising, as the marsh at Boundary Bay is much narrower than the other marshes. In the months when I did my survey, there were times I was out at Boundary Bay during high tide (or close to high tide), and the water was not close to reaching the marsh. This means that the marsh is exposed for the whole tidal cycle, which would allow more water to evaporate out of the soil (Wang et al., 2007). At Sea Island, there was a weak relationship between soil water and elevation, where higher elevation areas had a higher soil water content. One would expect that the higher elevation areas would have a lower soil water content, as these areas are exposed for longer during the tide cycle. This relationship at Sea Island shows that there is another factor besides elevation that impacts the level of soil water, which may be reflective of the particle sizes present in the soil. Unfortunately, particle size was not measured during this study because of time constraints.

4.2. Soil Pore Water Salinity

Salinity has been shown to be one of the key factors that influence plant distribution within a tidal marsh (Hutchison, 1982). The soil pore water salinity may be reflective of surface water salinity, but also the salts may have accumulated in higher concentrations in the soil. One would expect that as the elevation decreases, the soil water salinity would increase. This is because the lower elevation areas have more contact with ocean water, whereas higher elevation areas have less contact with ocean water, and more contact with freshwater (both from the Fraser River and pumping stations along the dike). At Sea Island, there was an insignificant relationship between elevation and soil pore water salinity. The northern three transects at Sea Island showed a trend of increasing soil pore water salinity with decreasing elevation. The southernmost transect, Sea Island 4, was the longest transect at Sea Island, and had a consistent soil pore water salinity measurement of around 20 ppt for each measurement location. I believe this is because the southernmost transect is close to the jetty at Sea Island, which changes the natural water flow pattern.

Lulu Island, Westham Island, Brunswick Point and Boundary Bay all showed a pattern of increasing soil pore water salinity with decreasing elevation. Lulu and Westham Island had a medium relationship, while Brunswick Point and Boundary Bay had a weak relationship. Increasing soil pore water salinity with decreasing elevation is the relationship I had expected to see at these four marshes. Westham Island and Brunswick Point had lower salinity values, while Boundary Bay had very high soil pore water salinity values.

4.3. Species Diversity

It is often presented in biological literature that higher species diversity areas are of higher ecological value. However, historical data shows that large monotypic stands, especially in lower elevation areas, are a sign of a natural, highly functioning tidal marsh in the Fraser River estuary (Yamanaka, 1975; Hutchison 1982, Boyd 1983). In addition, there are not as many plant species that can grow in a tidal marsh as compared to a forest, so the diversity of a tidal marsh will be inherently lower. All four of the brackish marshes showed a trend of decreasing species diversity with decreasing elevation. Sea Island, Lulu Island, and Westham Island all showed a weak relationship between diversity and elevation, while Brunswick Point showed an insignificant relationship. The relationship at Brunswick Point may have been lower because the shape of the marsh there is different than the other marshes; there is a long narrow strip of *S. pungens* that makes up the majority of the marsh. It is important to note that at Sea Island and Lulu

Island, there is *Z. japonica* present at lower elevation areas of the marsh. This plant was included in the diversity calculations of these two marshes, as were all other non-native species. There is also another non-native species present at lower elevation areas of these marshes, *Cotula cornopifolia*, that is included in the diversity calculations. The presence of these two non-native species in the lower elevation areas of the marshes means that the diversity is higher than it would be in historical conditions. It seems that the natural historical condition is to have primarily *S. pungens* as the low elevation species, with some *Isolepis cernua* and *Spergularia canadensis* mixed in as small understory species.

At Boundary Bay, there was an insignificant relationship between diversity and elevation. This may be because of the narrow elevation range of the marsh. Anecdotally, I observed that the marsh at Boundary Bay generally moves from an area of several shrub species, to a zone of *D. spicata* and *J. balticus*, to an area of *T. maritima* and *S. pacifica*. The higher elevation areas had more plant species in them, but this is not reflected in this graphical relationship. This is likely because the marsh at Boundary Bay has a narrower elevational range than the other four marshes.

4.4. Species Evenness

All five marshes had an insignificant relationship between species evenness and elevation. Evenness is an important parameter to examine in tidal marshes. It has been noted in many historical and present day observations that there is a large presence of monotypic stand communities within tidal marshes. Monotypic stand communities show a low evenness value, close to zero. The results of the evenness against the elevation show that there is no elevational preference for monotypic communities to develop within each marsh; the monotypic communities are spread evenly throughout (Sharpe and Baldwin, 2009).

4.5. Elevation Tolerance

Elevation is a key marker of where a plant is located within a marsh, and gives an indication of how long the location will be inundated for. There were certain plants that follow elevational trends over the brackish marshes. The plants that show a larger elevational range are more suited to restoration projects, as they can tolerate varying inundation levels. *S. pungens* and *B. maritimus*, when present, showed a large elevational range. *Z. japonica* showed overlap with *S. pungens* and *B. maritimus* at Sea Island and Lulu Island. *C. lyngbyei* also showed a large elevational range at Lulu Island, Westham Island, and Brunswick Point. *S. tabernaemontani* was present in more plots at Lulu Island than the other marshes, and it showed a large elevational range. At Boundary Bay, *D. spicata*, *S. pacifica*, and *T. maritma* had the highest elevational range. This indicates that these species can be more widely used in restoration projects in Boundary Bay (Belleveau, 2012; Mendelssohn and Kuhn, 2003).

4.6. Soil Water Tolerance

The ability of a plant to tolerate a wide range of soil water values means that it is more suited to certain restoration projects. *S. pungens* and *B. maritimus*, which both had wide elevational tolerance levels, both showed narrow soil water tolerance levels at the brackish marshes. These two species are then limited by the soil water level. *P. anserina, D. spicata*, and *C. lyngbyei* showed a larger range of soil water. These species are typically found in higher elevation areas, and therefore have to tolerate longer periods of no water during the tide cycle, and potentially high inundation due to pumping stations. At Boundary Bay, all the plants exhibited a similar soil water range. This may be due to the variable soil water levels and consistent particle sizes across Boundary Bay; the plants are not limited by this factor (Swinbanks and Murray, 1981).

4.7. Soil Pore Water Salinity Tolerance

Soil pore water salinity is a key measurement of whether a plant can survive at a certain location. Certain plants have greater ability to get rid of salts in the water that they uptake (Parida and Das, 2005). Plants that have a wide soil pore water salinity tolerance are good candidates for restoration projects where the salinity levels are high, or difficult to control. *B. maritimus* and *S. pungens* displayed a large salinity tolerance over Lulu and Westham Islands, as well as *C. lyngbyei* at Westham Island. *Z. japonica* also displayed an overlapping soil pore water salinity tolerance as *S. pungens* and *B. maritimus*. This is concerning, as it shows potential for this non-native species to advance further into the marsh, in areas that have lower salinity values (Sutherland, 2013). This is particularly relevant in areas that are now bare that were historically marsh, as plant species are typically limited in distribution in the upper marsh by competition (Pennings and Callaway, 1992). At Boundary Bay, *D. spicata, A. patula, S. pacifica,* and *T. maritima* had the largest soil pore water salinity tolerance, and would therefore be good target species for replanting. It would have been ideal to do a multi-variate analysis to show which of the three factors affected plant distribution the most, however, because the full seasonal variation of soil pore water salinity and soil water was not measured, and since soil pore size was not measured, it was decided not to do this analysis.

4.8. Plant Height and Density

Plant height and density are both indicators of plant health. A species that that has a relatively higher density and/or height at a certain location shows that it is experiencing better conditions at that location. The plant height and density were measured of the predominant species at each plot. Several plant species showed no relationship between density and elevation, or height and elevation, including *B. maritimus*, D. *spicata*, *J. balticus*, *Z. japonica*, and *S. pacifica*. This result of no relationship shows that although these plants are located at multiple elevations within the marsh, they can grow well at all elevations, and do not have a preference for a certain elevation (of the elevations that they were found in dominance in).

S. pungens showed an increasing height with increasing density relationship at all the marshes except at Sea Island, and decreasing density with increasing elevation relationship. This shows that at higher elevations, there are other plant species that compete with *S. pungens*. However, at lower elevations, it is one of a few plants that can persist, increasing its density. The height of *S. pungens* increased with increasing elevation, showing that it can grow taller at higher elevations. This means that although *S. pungens* can grow taller in the upper marsh, it is not able to achieve the same density as in the lower marsh, which may be because of salinity limitations (Pennings and Callaway, 1992).

C. lyngbyei showed an increase in height with increasing elevation (except at Lulu Island), and decreasing density with increasing elevation. This shows that *C. lyngbyei* is able to grow taller in areas with less inundation and lower soil pore water salinity.

However, in the upper marsh areas, there are more plant species growing, so it decreases its density.

S. tabernaemontani showed increasing density with increasing elevation at Westham and Lulu Islands. The two locations showed differing relationships in regard to height; at Westham Island height decreased with increasing elevation, and at Lulu Island height increased with increasing elevation. This shows that this species prefers to grow at higher elevation areas, and the height is variable across different marshes.

T. maritima showed increasing height with increasing elevation, and decreasing density with increasing elevation. This shows that this species can grow taller at higher elevations, but is more prevalent in lower elevations. This makes it a good species to plant at low elevation areas in salt marshes, as it can form monotypic stands.

4.9. Lulu Island Comparison

4.9.1. Plant Height

The t-test between average height in 1981 and 2018 shows that the height of *S. pungens* has significantly decreased in 2018. As height can be used as a proxy for plant health, this result is concerning. Coupling the plant height result with the decreased percent dominance of *S. pungens*, this suggests that this plant is not as healthy in 2018 as it was in 1981 (Balke, 2017). This decreased height may be a result of the less *S. pungens* presence in 2018 at Lulu Island. This result is also concerning, as there is less *S. pungens* in the marsh in 2018, and it is shorter. The height of *B. maritimus* was significantly taller in 2018 than in 1981. The percent dominance has not changed noticeably since 1981, but the taller *B. maritimus* may be a result of less *S. pungens* present in the marsh. With less large monotypic stands of *S. pungens* in 2018, there may have been an opportunity for *B. maritimus* to grow taller.

4.9.2. Percent Dominance Plant Trends

The percent dominance graphs presented for Lulu Island showed how *S. pungens* and *B. maritimus* have changed since 1981. *S. pungens* showed the most change (Figure 58). The lower percent dominance values in 2018 showed that there are now other species present with the *S. pungens*, whereas in 1981, it was the only species in those areas. This is concerning, as it shows that *S. pungens* may have less cover than before, but also that other species are taking over the area that it previously occupied. *B. maritimus* showed variability in the percent dominance of this species in both 1981 and 2018 (Figure 58). This variability shows that this plant has not changed much in percent predominance it occupies within the marsh.

The percent dominance maps that are presented show a good side by side comparison of how the transects at Lulu Island have changed since 1981. It is important to note that these transect comparisons do not take into account the amount of bare ground. For example, if there was one stem of one plant species present in the plot, it would count as 100% dominance. These side by side comparisons illustrate where the different plant species are located within the marsh. It is important to know that the 2018 transects were done in the same approximate location as the 1981 transects. Since the 1981 transects were not GPS located, they were given locations later based on memory of where they were located. Since the brackish marsh at Lulu Island is so variable, having a plot in a location 10 m away from where it was historically may result in a different plant community. However, if the side by side comparison shows that the plants are approximately the same, this likely means there is not a significant change.

The most obvious change from the comparison maps is the lack of *S. pungens* in 2018 on all the transects. There is also some *B. maritimus* that is missing, especially from transect 2, 3, 4, and 5. On transect 6, there is more *B. maritimus* than in 1981 in the lower elevation zones. The upper marsh zones are relatively similar on most transects. On transect 2 and 3, there is grass at lower elevations than in 1981. This is a concerning trend to see, as it shows the upper marsh is changing the elevation at which it is located. However, this may be a result of the quadrats being in slightly different locations than in 1981. Overall, the upper marsh has not changed in a noticeable and significant way from 1981 to 2018. This shows that the marsh recession has only noticeably affected the lower elevation areas of the marsh.

4.9.3. Other Trend Comparisons

At Lulu Island, Hutchison (1982) set up a study to capture the variability of plant zonation within the marsh and the corresponding soil parameters. Hutchison found that the salinity at Lulu Island was the lowest in the upper elevation zones of the marsh, which was attributed to influence from the pumping stations (1982). This was also generally true in my study, even though the salinity measurements were collected in different ways. It was found that the soil water was the highest in the high and middle marsh zones, and the low marsh zone experienced quick drainage during low tide because of the higher proportion of fine sand (Hutchison, 1982). This was reflected in my study, as the soil water tolerance of both *S. pungens* and *B. maritimus* was narrow at Lulu Island, and was lower than other species. My soil water results at Lulu Island do not reflect the observation that Hutchison made that the water content was the highest in the high and middle marsh zones, as I had an insignificant relationship between elevation and soil water at Lulu Island. This may be due to difference in sampling method, Hutchison (1982) tested for soil moisture in the lab, whereas I tested soil moisture with a field probe.

Hutchison proposed that the differences in abundance in the high and middle marsh zones could be attributed to factors besides elevation (1982). This is reflected in my results, as key high elevation species like *P. anserina*, *T. latifolia*, *D. spicata*, *C. lyngbyei*, and *S. tabernaemontani* varied in their preferred soil water and soil pore water salinity levels. It was observed that *S. pungens* distribution depended on soil pore size in the low marsh zones, and elevation and salinity variance in the high and middle marsh (Hutchison, 1982). At Lulu Island, *S. pungens* is the plant that has been the most impacted by the marsh recession. There are patches of *S. pungens* still remaining in the historic low marsh area, and I observed that these patches have generally sandier soil than areas that do not have *S. pungens.* If doing restoration activities in low elevation zones, the soil particle size should be an important factor if replanting *S. pungens* (Hutchison, 1982).

4.10. Yamanaka Comparison

The density comparison of key plant species in Yamanaka (1975) show that most of the species remain at about the same density. *P. anserina* and *S. tabernaemontani* had a higher density in 2018, and *T. maritma* had a higher density in 1973/74. It is interesting that *P. anserina* and *S. tabernaemontani* were at higher densities in 2018, but not especially relevant, as neither of these species are found in high quantities in the brackish marshes. The higher density of *T. maritma* in 1973/74 may be due to different counting methods, as this species has many leaves, making it difficult to determine where one plant begins and another ends.

It is interesting that Yamanaka's soil data at the brackish marshes shows a decreasing trend of conductivity with increasing distance from the dike. Conductivity is directly related to salinity, as conductivity is a measure of how well electrical current passes through water (CWT, 2004). A higher concentration of electrolyte (i.e. salt) results in a higher conductivity. My results from 2018 show a higher concentration of salt with increasing distance from the dike at the brackish marshes. This is the opposite result that Yamanaka saw. At Boundary Bay, Yamanaka's results show varied conductivity across the transects. This varied conductivity is also reflected in my results, with the Boundary Bay soil pore water salinity having a weak relationship with elevation.

4.11. Westham Island Marsh Recession

It is important to note the large area of marsh recession that has occurred at Westham Island; it is a patch of recession occurring in the lower elevations of the marsh that appears to have started from the middle of the marsh and spread outward (Balke, 2017). There were two of my transects (Westham Island 2 and 3) that passed through this area of recession. The lack of historical information on plant composition at Westham Island makes it difficult to know how this recession may have contributed to the plant communities changing at Westham Island. Yamanaka (1975) completed one transect at Westham Island, it is described as being off of Riefel Island. It is likely that this transect is north of the recession area (and therefore lines up more with my Westham Island 1 transect). The general findings of the transect from Yamanaka was that it moved from *T. latifolia*, to *C. lyngbyei* to *S. pungens*, with smaller communities of *B. maritimus*, *T. mariitma,* and *S. tabernaemontani* (1975). This was generally the pattern of plants that I observed at Westham Island as well. On the transects that crossed the area of recession, this same vegetation pattern is present, and *S. pungens* is present before and after the area of recession. It is difficult to say whether the *S. pungens* has moved to the landward side of the recession because the conditions have changed, or because it was always there, and some of the density has been lost.

4.12. Key Findings

There are several key findings to take away from this study and its results. The soil water and soil pore water salinity results illustrate that each marsh is unique, and should be treated independently during restoration efforts. Elevation and soil factors play a large role in determining where plants can grow. The evaluation of these factors prior to any restoration efforts is important. The same species exhibit different tolerances to the three environmental factors measured at different marshes. This shows how critical this data is to understand each marsh, and that additional environmental factors that perhaps cannot be measured easily play a role in determining distribution of plants. Although species diversity is an important biological measure, a high diversity does not necessarily reflect a healthy marsh system (Pennings and Callaway, 1992). Plant density and height is a good measure of where certain species grow best, although some species do not show a preference for a certain elevation through these measurements. Comparing where upper and lower marsh plant species are present/absent is a good way of illustrating changes in the marsh, and is important to keep monitoring over time (Hutchison 1982; Balke, 2017).

Chapter 5. Recommendations

5.1. Restoration Recommendations

There are many factors that need to be taken into consideration when making restoration recommendations for the marshes that were surveyed. Knowing where key plant species are currently located within each marsh is a crucial first step to restoration. The study that I completed provides a current, comprehensive survey of which species are present in each of the five marshes, and also shows key soil factors in determining the highly abundant species. These findings should be used as baseline data when planning any sort of restoration effort within the specific marsh. Each of the five marshes receive different ecological stressors, and restoration efforts should be unique to each marsh. However, there are other large-scale factors that need to be taken into consideration when planning for the long-term resilience of these marshes.

5.1.1. Competition

It has been established that competition between plant species plays a key role in where plants are located within tidal marshes (Pennings and Callaway, 1992). It has been found that the upper elevational limits of each plant species is determined by competition, and the lower elevational limits are determined by the tolerance level of the species to various environmental factors (Pennings and Callaway, 1992). If competition is taken out of the picture, tidal marsh plant species grow the best in fresher marshes (Crain et al, 2004). These findings from the above researchers are also apparent in my study, even though competition between species was not directly measured. The high marsh zones of each marsh were crowded with multiple plant species; this is apparent from the diversity graphs, as well as the list of species from the upper marsh areas. The lower marsh zones were dominated by a few species, which illustrates that in this zone is limited by environmental factors. When planning for restoration efforts in low elevational zones, the environmental factors need to be taken into consideration more than in the high elevation zones.

5.1.2. Sea Level Rise

The cities in the Fraser River delta front are planning for 1 m of sea level rise by the year 2100 (City of Vancouver, 2018). The looming potential impact of sea level rise has cities looking at options to mitigate these effects, including changing land use, building larger dikes, and expanding coastal marshes (NCCARF, 2016). Elevation is a key factor in determining distribution and presence of plants within a tidal marsh. Tidal marshes accrete vertically naturally to account for sea level rise. Accretion rates vary between marshes, but at Lulu Island, accretion rates have been measured between 2.6 and 8.5 mm/year since 1940 (Kirwan and Murray, 2008). The Fraser River delta subsides between 1.5 and 2 mm/year, and historically, accretion rates have been able to keep up with sea level rise (Church and Hales 2007; Kirwan and Murray, 2008). However, with projected increased sea level rise in the next century, it is predicted that the Fraser River intertidal marshes will not be able to keep up (Kirwan and Murray, 2008). When sea level rise happens, the natural response of the marsh is to migrate landward. The increased inundation in lower elevation areas creates soil changes that make the area unsuitable for plants (Warren and Niering, 1993). However, because the Fraser River delta is highly diked, these marshes are unable to migrate landward (Kirwan and Murray, 2008). Under one model prediction of a sea level rise scenario, the current dike structures in the Fraser River delta would result in 70% of vegetation loss in the marshes (Kirwan and Murray, 2008).

5.1.3. Sedimentation

The natural sediment deposition pattern has been changed in the Fraser River delta. The majority of sediment from the Fraser River flows through the main channel, and the sediment plume is naturally pulled northwards towards Lulu Island, but the Steveston Jetty blocks much of the depositional pattern (Barrie and Currie, 2000). The Steveston Jetty also prevents freshwater from the Fraser River from reaching Lulu Island in the historic manner (Levings, 1980). Westham Island and Brunswick Point receive very little, if any, of the sediment plume from the Fraser River (Barrie and Currie, 2000). It has been shown that tidal marshes can vertically accrete by organic matter accumulation, so sediment deposition at Westham Island and Brunswick Point may not be a necessary mechanism for vertical accretion (Nyman et al., 2006). There are plans to breach dikes, jetties, and causeways in several strategic locations around the Fraser River delta to increase fish utilization of the marshes (Raincoast Conservation Foundation, 2018), so it will be important to monitor plant communities and soil properties near these dike breaches, to see if these breaches have other positive effects for the marshes.

One strategy to combat accelerated sea level rise is to add layers of sediment on top of the existing marsh. It has been found that the deposits should be less than 15 cm; if the deposits are thicker than that, the vegetation will be smothered (Ford et al.,1999). Increased sediment on a coastal marsh results in higher biomass production, and better soil aeration (Mendelssohn and Kuhn, 2003). Free sulfide is a plant toxin that inhibits growth, that is produced by anaerobic bacteria in reduced soils (Mendelssohn and Kuhn, 2003). The introduction of additional sediment causes the soils to become more oxidized, reducing toxic conditions for plants (Mendelssohn and Kuhn, 2003). Many projects use dredge spoils to raise the elevation of the marsh; if this is a project that would be undertaken, it is important to ensure that the spoils are low in potential plant toxins, and also contain the correct particle sizes to closely match up with the marshes. It is also important to not inadvertently create terrestrial conditions by raising the elevation of the marsh too high, where the inundation effects are negligible and the litter decomposition rates increase (Moody, 1978).

5.1.4. Replanting Efforts

The conditions and time of year that seedlings are planted for restoration have a direct impact on survival. If possible, seedlings and seeds should be planted during a disturbance free period to promote germination and establishment (Silinski et al., 2016). It is suggested to use the fastest growing species for initial establishment within the marsh, and to temporarily alter site conditions to promote growth (Balke et al., 2013). However, if replanting is required in low elevation areas, the list of species that occur there naturally is short, so there may not be a choice of fast growing species to promote establishment. Within intertidal marshes, natural processes contribute strongly to the species present, and starting a marsh on the trajectory towards restoration may be enough to complete the desired restoration (Weinstein and Kreeger, 2002). However, the presence of dikes can discourage this natural restoration pathway from happening (Weinstein and Kreeger, 2002). Since the Fraser River delta is highly diked, this means that any large-scale restoration effort may need to be managed more heavily than in an undiked area. The main limiting nutrient in salt marshes is nitrogen, and it is often lacking in restored marshes (Mendelssohn and Kuhn, 2003; Weinstein and Kreeger, 2002).

However, it is important to consider whether one is aiming to restore to historical conditions, or maintain current conditions. It is apparent that the marshes have experienced changing conditions since the last plant surveys were done (Balke, 2017), so restoring to these historical conditions may not be possible. Any sort of restoration effort that would involve changing the conditions at the marshes would be very costly. If restoration efforts are undertaken, I recommend using the current plant distribution that I observed in this study as the basis, as these plant distributions are based on the current conditions at each of the sites.

5.1.5. Grazing

The populations of overwintering snow geese and resident Canada geese that occupy the Fraser River delta front are expanding and impacting the tidal marshes. Snow geese graze by removing the root of the plant (grubbing), and leave the remaining 90% of the plant (Smith and Odum, 1981). Snow geese have found to significantly lessen the biomass in grazed areas versus ungrazed areas (Smith and Odum, 1981). In the Fraser River delta, it was found that the absence of snow geese grubbing increased rhizome mass of *S. pungens* (Boyd, 1995). It has been found that any newly replanted areas need to have goose exclosures, otherwise the plants will be grazed (Balke, 2017). The high populations of these geese that grub in the marshes have, and will continue to impact the Fraser River delta marshes. The exclusion of geese from recently planted areas will be a necessity, and looking into longer term population control may be a necessity to ensure the long-term survival of these marshes.

5.1.6. Successional Patterns

Successional patterns and stages should be kept in mind when planning restoration work. It is suggested in some literature that *S. pungens* and *B. maritimus* are the primary colonizing species of a tidal marsh area, and then *C. lyngbyei* and other further upland species are secondary colonizers (Hutchison, 1982). There are well studied and established models of succession for marshes in Washington, Oregon, and California, but it is important to keep in mind that these marshes experience the freshest flows earlier in the season than the Fraser River delta does because the Fraser River is snowmelt fed, and the other rivers are rain fed (Hutchison, 1982). The Fraser River intertidal marshes do have similar vegetation to these more southern marshes, but the unique river system makes it important to base restoration decisions on patterns of vegetation planting on the information of the marshes in the Fraser River delta.

5.1.7. Non-Native Species

A factor that must be taken into consideration when planning any sort of restoration work is the presence of non-native plant species. The marshes in the Fraser River delta front are reasonably free of non-native species, but there are a few key species to be considered. Firstly, the non-native grass *Spartina spp.* has become a large problem in the intertidal marshes of the west coast of the United States, and pre-emptive eradication methods in Fraser River delta have kept it at low levels so far, but this effort needs to be continued to prevent full invasion. This grass is a sediment accumulator, and may fundamentally change the structure of the marsh if present in high enough quantities (Buchanan, 2003). Secondly, purple loosestrife (*Lythrum salicaria*) is an aggressive wetland invader that is present in some of the marshes, and was found the most often at Westham Island in this study. *L. salicaria* typically prefers freshwater environments, and can also change the local hydrology (Invasive Species Council of BC, 2017). It has not formed large monotypic stands in any of the marshes, but this plant needs to be monitored to ensure this does not happen. Thirdly, *Z. japonica* is present in low elevation areas of Lulu Island and Sea Island, and is especially present in the areas of Lulu Island where marsh recession has occurred. *Z. japonica* can colonize higher elevation areas than the native eelgrass *Z. marina*, and can change the habitat by reducing invertebrates and biofilm, negatively affecting several bird species (Sutherland, 2013). It has also been shown that *Z. japonica* thrives in areas of disturbance, and may cause local sediment size reductions (Bando, 2006; Posey, 1988). *Z. japonica* was often found mixed in with other low elevation marsh species. It is imperative to continue monitoring the presence of *Z. japonica* within the marsh, to ensure it is not taking over areas that were previously occupied by *S. pungens* and *B. maritimus*.

5.2. Monitoring Recommendations and Future Studies

The importance of continued monitoring and studies of plant distribution within these marshes cannot be stressed enough. These marshes are a unique and critical part of the Pacific Coast ecosystem, and it is important to know how changing environmental factors are influencing plant distribution. It is important to know where the leading edge of the marsh is to monitor if recession is happening, but it is also important to know where the plant zones are located within the marsh. If the low elevation plants are migrating landward, this is concerning, as it means that sea level rise is squeezing the marsh between the dike and the rising ocean.

There are two possibilities for general categories of future plant studies that can be done: large-scale drone surveys, and small scale, detailed quadrat surveys. Drone surveys can be done to show large predominant plant zones. The predominant plants are often a slightly different colour of green, so they could be delineated on drone imagery (Cruzan et al., 2016). Having the high-resolution drone imagery would be advantageous in delineating between species. However, drone surveys will not show how understory species are changing, or how height and stem density are changing. Detailed quadrat surveys should be conducted at least every 10 years to quantify any shifts. The imminent dike and jetty breaches that are happening in the Fraser River delta will provide an interesting area to do plant studies, as the changing water and sediment dynamics may alter the vegetation communities. The study that I completed will be a good starting place to evaluate the five marshes, and provide a good long-term monitoring plan. This study quite labor intensive, and needs to be completed over a short period of time to capture the full plant growth before senescence. There could be more soil parameters added to the study to further quantify factors that affect plant distribution, such as pH, organic matter content, nutrient levels, and conductivity. If possible, it would be beneficial to do the soil analyses in a laboratory setting to provide a standardized, precise measurement. It would also be beneficial to capture the soil pore water salinity over the whole growing season. I measured the soil pore water salinity at the end of the growing season; likely when the salinity was the highest. However, the soil pore water salinity is likely lower during the majority of the growing season, so measuring what salinity the plant experiences for most of the season would show what it prefers to grow in, not just what it can tolerate at the end of the season.

Literature Cited

Adams, M.A. 2002. Shoreline Structures Environmental Design: A Guide for Structures Along Estuaries and Large Rivers. Fisheries and Oceans Canada, Vancouver, BC and Environment Canada, Delta, BC.

Adams, M.A., and Williams, G.L. 2004. Tidal marshes of the Fraser River estuary: composition, structure, and a history of marsh creation efforts to 1997; in Fraser River Delta, British Columbia: Issues of an Urban Estuary, (ed.) B.J. Groulx, D.C. Mosher, J.L.Luternauer, and D.E. Bilderback; *Geological Survey of Canada,* Bulletin 567: 147-172.

Atkins, R.J., Tidd, M., and Ruffo, G. 2016. Sturgeon Bank, Fraser River Delta, BC, Canada: 150 Years of Human Influences on Salt Marsh Sedimentation. *Journal of Coastal Research* 75: 790-794.

Bakker, J.P., Esselink, P., Dijkema, K.S., van Duin, W.E., and de Jong, D.J. 2002. Restoration of Salt Marshes in the Netherlands. *Hydrobiologia* 478: 29-51.

Baldwin, J.R., and Lovvron, J.R. 1994. Expansion of seagrass habitat by the exotic *Zostera japonica*, and its use by dabbling ducks and brant in Boundary Bay, British Columbia. *Marine Ecology Progress Series* 103: 119-127.

Balke, T., Webb, E.L., van den Elzen, E., Galli, D., Herman, P.M.J., and Bouma, T.J. 2013. Seedling Establishment in a Dynamic Sedimentary Environment: A Conceptual Framework Using Mangroves. *Journal of Applied Ecology* 50: 740-747.

Balke, E. 2017. Investigating the role of elevated salinity in the recession of a large brackish marsh in the Fraser River estuary. Master of Science Thesis. Simon Fraser University and British Columbia Institute of Technology.

Bando, K.J. 2006. The roles of competition and disturbance in a marine invasion. *Biological Invasions* 8: 755-763.

Barrie, J. V. 2000. Recent Geological Evolution and Human Impact: Fraser Delta, Canada in *Coastal and Estuarine Environments: sedimentology, geomorphology, and geoarchaeology* 175: 281-292.

Barrie, J.V., and Currie, R.G. 2000. Human Impact on the Sedimentary Regime of the Fraser River Delta, Canada. *Journal of Coastal Research* 16(3): 747-755.

Belleveau, L. 2012. Determining the influence of soil salinity and tidal inundation on the growth, distribution, and diversity of salt marsh vegetation: implications for the restoration of the Nisqually Delta, Washington. MES Thesis, Evergreen State College.

Boyd, W.S. 1983. Results of a 1981 Ecological Survey of the Lulu Island Foreshore Marshes. Canadian Wildlife Service. Environment Canada.

Boyd, W.S. 1995. Lesser Snow Geese (*Anser C. caerulescens*) and American Three-Square Bulrush (*Scirpus americanus*) on the Fraser and Skagit River Deltas. Doctor of Philosophy Thesis, Simon Fraser University.

Boyd, W.S., McKibbin, R., and Moore, K. 2011. The bulrush marshes of the Fraser River Delta have undergone significant changes between 1989 and 2011. Unpublished data.

Buchanan, J.B. 2003. Spartina invasion of Pacific coast estuaries in the United States: Implications for shorebird conservation. *Wader Study Group Bulletin* 100: 47-49.

Charpentier, A., Mesleard, F., and Thompson, J.T. 1998. The Effects of Rhizome Severing on the Clonal Growth and Clonal Architecture of *Scirpus maritimus*. *Oikos* 83(1): 107-116.

Church, M. 2017. Fraser River: History in a Changing Landscape in *Landscapes and Landforms of Western Canada*. Springer International Publishing, Switzerland.

Church, M., and Hales, W. 2007. Tidal Marshes of the Fraser Delta 75 Years of Growth and Change. *Discovery* 36(1): 29-33.

City of Vancouver, 2018. Coastal Adaptation Plan: Fraser River Foreshore. Accessed 20 March 2019 at https://vancouver.ca/files/cov/coastal-adaptation-plan-final-report.pdf

Clean Water Team (CWT). 2004. Electrical conductivity/salinity Fact Sheet, FS-3.1.3.0(EC). In: The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment, Version 2.0. Division of Water Quality, California State Water Resources Control Board (SWRCB), Sacramento, CA.

Crain, C.M., Silliman, B.R., Bertness, S.L., and Bertness, M.D. 2004. Physical and Biotic Drivers of Plant Distribution across Estuarine Salinity Gradients. *Ecology* 85(9): 2539-2549.

Cruzan, M.B., Weinstein, B.G., Grasty, M.R., Kohrn, B.F., Hendrickson, E.C., Arredondo, T.M., and Thompson, P.G. 2016. Small Unmanned Aerial Vehicles (Micro-UAVs. Drones) in Plant Ecology. *Applications in Plant Sciences* 4(9): 1600041.

Douglas, G.W., Straley, G.B., Meidinger, D.V., and Pojar, J. (editors). 1998. *Illustrated Flora of British Columbia. Volume 2: Dicotyledons (Balsaminaceae Through Cucurbitaceae).* B.C. Ministry of Environment, Lands & Parks and B.C. Ministry of Forests. Victoria. 401 p

Douglas, G.W., D.V. Meidinger and J. Pojar (editors). 2001. *Illustrated Flora of British Columbia, Volume 6: Monocotyledons (Acoraceae Through Najadaceae*). B.C. Ministry. Environment, Lands and Parks and B.C. Ministry of Forests. Victoria.

Ewing, K. 1986. Plant Growth and Productivity along Complex Gradients in a Pacific Northwest Brackish Intertidal Marsh. *Estuaries* 9(1): 49-62.

Ford, M.A., Cahoon, D.R., Lynch, J.C. 1999. Restoring marsh elevation in a rapidly subsiding salt marsh by thin-layer deposition of dredged marsh. *Ecological Engineering* 12: 189-205.

Google Imagery. 2018. https://www.google.com/maps. [Accessed 3 December 2018].

Hutchison, I. 1982. Vegetation-Environment Relations in a Brackish Marsh, Lulu Island, Richmond, B.C. Department of Geography, Simon Fraser University.

Hutchison, I. No Date. Salinity Tolerance of Plants of Estuarine Wetlands and Associated Uplands. Washington State Shorelands and Coastal Zone Management Program: Wetlands Section.

Hutchison, I. and Smythe, S. R. 1988. Impacts of Commercial Harvesting of Sea-Asparagus on the Productivity of Coastal Salt Marshes in B.C. Ministry of Agriculture, Province of British Columbia.

Invasive Species Council of BC. 2017. Purple Loosestrife Fact Sheet. Accessed 20 March 2019 at https://bcinvasives.ca/documents/Purple_Loosestrife_TIPS_2017_WEB.pdf

Janousek, C.N., Buffington, K.J., Thorne, K.M., Gutenspergen, G.R., Takekawa, J.Y., and Dugger, B.D. 2016. Potential Effects of Sea-Level Rise on Plant Productivity: Species-Specific Responses in Northeast Pacific Tidal Marshes. *Marine Ecology Progress Series* 548: 111-125.

Kirwan, M.L., and Murray, AB. 2008. Ecological and Morphological Response of Brackish Tidal Marshland to the Next Century of Sea Level Rise, Westham Island, British Columbia. *Global and Planetary Change* 60: 471-486.

Klinkenberg, B. (Editor) 2018. *Zostera japonica. E*-Flora BC: Electronic Atlas of the Flora of British Columbia [eflora.bc.ca]. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver. [Accessed 4 December 2018].

Levings, C.D. 1980. Consequences of training walls and jetties for aquatic habitats at two British Columbia Estuaries. *Coastal Engineering* 4: 111-136.

Levings, C.D., Conlin, K., and Raymond, B. 1991. Intertidal Habitats Used by Juvenile Chinook Salmon (*Oncoyhynchus tshawytscha*) Rearing in the North Arm of the Fraser River Estuary. *Marine Pollution Bulletin* 22(1): 20-26.

Leuternauer, J.L., and Finn, W.D.L. Stability of the Fraser River Delta Front. *Canada Geotech.* 20: 603-616.

Mendelssohn, I.A., and Kuhn, N.L. 2003. Sediment Subsidy: Effects on Soil-plant responses in a rapidly submerging coastal salt marsh. *Ecological Engineering* 21: 115-128.

Moody, A. I. 1978. Growth and Distribution of the Vegetation of a Southern Fraser Delta Marsh. Master of Science Thesis, University of British Columbia.

NCCARF. 2016. What are the options for adapting to sea-level rise? Accessed 29 March 2019 at https://coastadapt.com.au/sites/default/files/infographics/15-117-NCCARFINFOGRAPHICS-5-03%2812Apr%29-UPLOADED.pdf

Nynam, J.A., Walters, R.J., Delaune, R.D., and Patrick, W.H.Jr. 2006. Marsh vertical accretion via vegetative growth. *Estuarine, Coastal and Shelf Science* 69: 370-380.

Parida, A.K., and Das, A.B. 2005. Salt tolerance and salinity effects on plants: a review. *Ecotoxicology and Environmental Safety* 60: 324-349.

Patridge, T.R. and Wilson, J.B. Methods for Investigating Vegetation/Environmental Relations – A Test Using the Salt Marsh Vegetation of Orago, New Zealand. *New Zealand Journal of Botany* 27(1): 35-47.

Pennings, S.C., and Callaway, R.M. 1992. Salt Marsh Plant Zonation: The Relative Importance of Competition and Physical Factors. *Ecology* 73(2): 681-690.

Pojar, J., and MacKinnon, A. (eds.). 1994. Plants of Coastal British Columbia, including Washington, Oregon & Alaska. Lone Pine Publishing, Vancouver, B.C.

Posey, M.H. 1988. Community Changes Associated with the Spread of an Introduced Seagrass, *Zostera japonica*. *Ecology* 69(4): 974-983.

Raincoast Conservation Foundation. 2018. Fraser River Estuary Connectivity Project. Accessed 29 March 2019 at https://www.raincoast.org/fraser-river-estuary-project/

Sharpe, P.J., and Baldwin, A.H. 2012. Tidal Marsh Plant Community Response to Sea-Level Rise: A Mesocosm Study. *Aquatic Botany* 101: 34-40.

Sharpe, P.J., and Baldwin, A.H. 2009. Patterns of Wetland Plant Species Richness Across Estuarine Gradients of Chesapeake Bay. *Wetlands* 29(1): 225-235.

Shaw, A., Lintern, D.G., Hill, P.R., and Houser, C. 2006. Factors Controlling Tidal Flat Response to Sea Level Rise: Roberts Bank, British Columbia, Canada. Coastal Dynamics 2005 – Proceedings of the Fifth Coastal Dynamics International Conference.

Silinski, A., van Belzen, J., Fransen, E., Bouma, T.J., Troch, P., Meire, P., and Temmerman, S. 2016. Quantifying Critical Conditions for Seaward Expansion of Tidal Marshes: A Transplantation Experiment. *Estuarine, Coastal and Shelf Science* 169: 227-237.

Smith, T.J., and Odum, W.E. 1981. The Effects of Grazing by Snow Geese on Coastal Salt Marshes. *Ecology* 62(1): 98-106.

Sutherland, T.F., Elner, R.W., O'Neill, J.D. 2013. Roberts Bank: Ecological crucible of the Fraser River estuary. *Progress in Oceanography* 115: 171-180.

Swinbanks, D.D., and Murray, J.W. 1981. Biosedimentological zonation of Boundary Bay tidal flats, Fraser River Delta, British Columbia. *Sedimentology* 28: 201-237.

Turner, N.J., and Kuhnlein, H.V. 1982. Two Important "Root" Foods of the Northwest Coast Indians: Springbank Clover (*Trifolium wormskilodii*) and Pacific Silverweed (*Potentilla anserine* ssp. *pacifica*). *Economic Botany* 36(4): 411-432.

Wang, H., Hsieh, Y.P., Harwell, M.A., and Huang, W. 2007. Modeling soil salinity distribution along topographic gradients in tidal salt marshes in Atlantic and Gulf coastal regions. *Ecological Modelling* 201: 429-439.

Warren, R.S., and Niering, W.A. 1993. Vegetation Change on a Northeast Tidal Marsh: Interaction of Sea-Level Rise and Marsh Accretion. *Ecology* 74(1): 96-103.

Weinstein, M.P., and Kreeger, D.A (eds.). 2002. Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, New York.

Yamanaka, K. 1975. Primary Productivity of the Fraser River Delta Foreshore: Yield Estimates of Emergent Vegetation. Master of Science Thesis. University of British Columbia.

Appendix A: List of Species Observed

Table 5. Species observed at Boundary Bay in 2018 survey.

Latin Name	Common Name
Achillea millefolium	Yarrow
Agropyron repens	Quackgrass
Agrostis exarata	Spike Bentgrass
Anthemis cotula	Mayweed
Atriplex patula	Orache
Convolvulvus arvensis	Bindweed
Cuscuta spp.	Dodder
Distichlis spicata	Salt Grass
Fucus distichus	Rockweed
Grindelia stricta	Gumweed
Hordeum jubatum	Foxtail Barley
Hypochaeris radicata	Hairy Cat's Ear
Juncus balticus	Baltic Rush
Lathyrus palustris	Marsh Pea Vine
Phalaris arundinacea	Reed Canary Grass
Rumex sp.	Dock
Zostera japonica	Japanese eelgrass
Zostera marina	Eelgrass

Table 6. Species observed at Brunswick Point during 2018 survey.

Latin Name	Common Name
Agrostis exarata	Spike bentgrass
Bolboschoenus maritimus	Seacoast Bulrush
Carex lyngbyei	Lyngbye's Sedge
Eleocharis palustris	Spike Rush
Isolepis cernua	Isolepis
Juncus balticus	Baltic Rush
Lythrum salicaria	Purple Loosestrife
Potentilla anserina	Silverweed
Rumex sp.	Dock
Sagittaria latifolia	Wapato
Schoenoplectus pungens	Common Three-Square Bulrush
Schoenoplectus tabernaemontani	Softstem Bulrush
Sium suave	Water Parsnip
Symphyotrichum subspicatum	Douglas Aster
Triglochin maritima	Seaside Arrowgrass
Typha angustifolia	Cattail
Typha latifolia	Cattail

Table 7. Species observed at Westham Island in 2018 survey.

Latin Name	Common Name
Agrostis exarata	Spike bentgrass
Bolboschoenus maritimus	Seacoast Bulrush
Carex lyngbyei	Lyngbyes Sedge
Cotula cornopifolia	Brass Buttons
Eleocharis palustris	Spike Rush
Glaux martiima	Sea Milkwort
Iris pseudacorus	Yellowflag Iris
Isolepis cernua	Isolepis
Lathyrus palustris	Marsh Peavine
Lythrum salicaria	Purple Loosestrife
Potentilla anserina	Silverweed
Rumex sp.	Dock
Ruppia maritima	Widgeon Grass
Sagittaria latifolia	Wapato
Schoenoplectus pungens	Common Three-Square Bulrush
Schoenoplectus tabernaemontani	Softstem Bulrush
Sium suave	Water Parsnip
Symphyotrichum subspicatum	Douglas Aster
Typha angustifolia	Cattail
Typha latifolia	Cattail
Triglochin maritima	Sea Arrowgrass

Table 8. Species observed at Lulu Island in 2018 survey.

Latin Name	Common Name
Ammophila arenaria	European Beachgrass
Atriplex patula	Orache
Agrostis exarata	Spike Bentgrass
Bellis perennis	English Daisy
Bolboschoenus maritimus	Seacoast bulrush
Carex lyngbyei	Lyngbye's Sedge
Cotula cornopifolia	Brass Buttons
Distichlis spicata	Salt Grass
Eleocharis palustris	Spike Rush
Glaux maritima	Sea milkwort
Hordeum jubatum	Foxtail Barley
Iris pseudacorus	Yellow Flag Iris
Isolepis cernua	Isolepis
Lathyrus palustris	Marsh Peavine
Lythrum salicaria	Purple loosestrife
Potentilla anserina	Silverweed
Rumex sp.	Dock
Schoenoplectus tabernaemontani	Softstem Bulrush
Schoenoplectus pungens	Common Three-Square Bulrush
Sonchus asper	Prickly Sow Thistle

Table 9. Species observed at Sea Island in 2018 survey.

Latin Name	Common Name
Agropyron repens	Quackgrass
Agrostis exarata	Spike Bentgrass
Atriplex patula	Orache
Bolboschoenus maritimus	Seacoast Bulrush
Carex lyngbyei	Lyngbye's Sedge
Cotula cornopifolia	Brass Buttons
Distichlis spicata	Salt Grass
Eleocharis palustris	Spike Rush
Hordeum jubatum	Foxtail Barley
Isolepis cernua	Isolepis
Potentilla anserina	Silverweeed
Schoenoplectus pungens	Common Three-Square Bulrush
Sonchus asper	Prickly Sow Thistle
Triglochin maritima	Sea Arrowgrass
Ulva spp.	Sea Lettuce
Zostera japonica	Japanese Eelgrass