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

By

Lisa Belleveau

A Thesis
Submitted in partial fulfillment
of the requirements for the degree
Master of Environmental Study
The Evergreen State College
2012

This Thesis for the Master of Environmental Study Degree by Lisa J. Belleveau has been approved for The Evergreen State College by:

____

Gerardo Chin-Leo, Ph.D.
Member of the Faculty

____

Kelley Turner, M.S.
Restoration Biologist
USGS Western Ecological Research Center

____

Jean E. Takekawa
Refuge Manager
Nisqually National Wildlife Refuge Complex

____

Date

ABSTRACT

Estuaries are biologically productive and diverse ecosystems that protect inland areas from flooding, filter fresh water entering marine waters, and provide economic, recreational, and aesthetic value. The Nisqually Delta in Washington State is an estuary that has been modified by restricting tidal flow to reclaim tidal lands for agriculture. Recently, the Nisqually National Wildlife Refuge, working in collaboration with the Nisqually Indian Tribe and Ducks Unlimited, restored a large amount of the tidal flows as part of the largest estuary tidal marsh restoration project in the Pacific Northwest. This thesis contributes to understanding vegetation response to estuary restoration by determining the elevation and pore-water salinity field conditions for nine common salt marsh species in the Nisqually Delta: *Carex lyngbyei*, *Distichlis spicata*, *Grindelia integrifolia*, *Jaumea carnosa*, *Juncus balticus*, *Potentilla anserina*, *Salicornia virginica*, *Spergularia sp.*, and *Triglochin maritimum*. Vegetation surveys were conducted from March to September of 2010 at 21 plots to measure growth over time. In August of 2010 an additional 30 plots were surveyed to estimate peak growth. At each of the plots, pore-water salinity, substrate elevation (as an indicator of submergence time), as well as percent cover, stem density, and maximum height was measured for each species. Using these data, the elevation and salinity range of each species was determined. Correlation analysis was conducted to explore the relationships among biological (percent cover, height, and density) and physical parameters (salinity and elevation). The seasonal plots were analyzed by establishing salinity and elevation zones and investigating the growth patterns within these zones over time. Overall, pore-water salinity and elevation had a positive influence on the salt marsh vegetation species studied. These species can tolerate high salinities, but submergence time (i.e. elevation) may be the dominant factor explaining differences in their growth and distribution. This research provides knowledge that can be used to identify suitable locations for salt marsh habitat restoration, and to ensure successful colonization of native species. Future research suggestions include continued monitoring of the Nisqually Delta vegetation along with the sedimentation and subsidence processes that affect their distribution and colonization success.

TABLE OF CONTENTS

List of Figures………………………………………………………………………….vi

List of Tables…………………………………………………………………….……..x

Acknowledgements………………………………………….…………………….xi

INTRODUCTION……………………………………………...……………….1

1.1 Research Significance and Project Summary………………………………………1

1.2 Nisqually River History……………………………………...……………….. 4

1.3 Recent Nisqually Delta History…………………………………………….....5

1.4 Management of the Nisqually Delta……………………………………..………9

1.5 Salinity and its effects on vegetation growth……………………..............................11

1.6 Elevation and its effects on vegetation distribution…………………….…………12

1.7 Vegetation Studies of the Nisqually Delta……………………………...………13

1.8 Vegetation Descriptions………………………………………………...………16

1.9 Research Question and Hypotheses…………………………………………….…20

2. METHODS……………………………………………………………..……..22

2.1 Study site……………………………………………………………..……………22

2.2 Survey methods…………………………………………………..…………..23

2.2.1 Vegetation……………………………………………………..……………. 23

2.2.2 Soil Pore-Water Salinity………………………………………….…………..25

2.2.3 Elevation………………………………………………………………..……26

2.3 Statistical analysis……………………………………………………………26

3. RESULTS and DISCUSSION……………………………………….………..28

3.1 Soil pore-water salinity and elevation at the study sites……………………………..28

3.2 Salinity Ranges of Nisqually salt marsh vegetation…………………………..……..32

3.3 Elevation Ranges of Nisqually salt marsh vegetation……………………..…...…….35

3.4 Analysis of Vegetation Growth across Salinity and Elevation Gradients………...…38

3.4.1 *Carex lyngbyei*…………………………………………………………..……41

3.4.2 *Distichlis spicata*………………………………………………………..… 45

3.4.3 *Grindelia integrifolia*…………………………………...……………………49

3.4.4 *Jaumea carnosa*………………………………...………………………………53

3.4.5 *Juncus balticus*……………………………………………..………………57

3.4.6 *Potentilla anserina*……………………………...……………….……………61

3.4.7 *Salicornia virginica*………………………...….…………………….………….65

3.4.8 *Spergularia sp*………………………………...………………………...….69

3.4.9 *Triglochin maritimum*…………………………………………………..…….72

3.5 Comparison of expected tolerance levels and Nisqually results…………………... 75

3.6 Species Richness……………………………………………………………..77

3.7 Site Conditions of the Restoration Area on the Nisqually National Wildlife Refuge.79

4. CONCLUSION and RECOMMENDATIONS………………………………...…..85

Literature Cited………………………………………………………………..88

List of Figures:

Figure 1: Location of the Nisqually estuary in Washington State………………………...3

Figure 2: The four study locations within the Nisqually Delta……………………………8

Figure 3: Monitoring locations within the Nisqually Delta……………………………...29

Figure 4: Salinity and elevation gradients of all four study sites (REF, P1, P2, and AS).30

Figure 5 (a & b): Soil pore-water salinity and elevation of the plots located within the marine marshes…………………………………………………………………………..31

Figure 6 (a & b): Soil pore-water salinity and elevation of the plots located within the brackish marshes…………………………………………………………………………32

Figure 7: Soil pore-water salinity of all species observed on the Nisqually Delta in the vegetation surveys of 2010………………………………………………………………34

Figure 8: Elevation of all species observed on the Nisqually Delta in the vegetation surveys of 2010…………………………………………………………………………..37

Figure 9: Kendall's correlation analysis of *Carex lyngbeyi* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta……………...43

Figure 10: Seasonal growth patterns of *Carex lyngbyei* across salinity and elevation gradients within the Nisqually Delta……………………………………………………..44

Figure 11: Soil pore-water salinity and elevation of the plots where *Carex lyngbyei* was present…………………………………………………………………………………45

Figure 12: Kendall's correlation analysis of *Distichlis spicata* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta……………...47

Figure 13: Seasonal growth patterns of *Distichlis spicata* across salinity and elevation gradients within the Nisqually Delta…………………………………………………..48

Figure 14: Soil pore-water salinity and elevation of the plots where *Distichlis spicata* was present…………………………………………………………………………………49

Figure 15: Kendall's correlation analysis of *Grindelia integrifolia* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta…………51

Figure 16: Seasonal growth patterns of *Grindelia integrefolia* across salinity and elevation gradients within the Nisqually Delta……………………………………….52

Figure 17: Soil pore-water salinity and elevation of the plots where *Grindelia integrefolia* was present……………………………………………………………………………….53

Figure 18: Kendall's correlation analysis of *Jaumea carnosa* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta……………...55

Figure 19: Seasonal growth patterns of *Jaumea carnosa* across salinity and elevation gradients within the Nisqually Delta…………………………………………………..56

Figure 20: Soil pore-water salinity and elevation of the plots where *Jaumea carnosa* was present…………………………………………………………………………………57

Figure 21: Kendall's correlation analysis of *Juncus balticus* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta……………...59

Figure 22: Seasonal growth patterns of *Juncus balticus* across salinity and elevation gradients within the Nisqually Delta.……………………………………………………….60

Figure 23: Soil pore-water salinity and elevation of the plots where *Juncus balticus* was present…………………………………………………………………………………61

Figure 24: Kendall's correlation analysis of *Potentilla anserina* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta……………...63

Figure 25: Seasonal growth patterns of *Potentila anserina* across salinity and elevation gradients within the Nisqually Delta……………………………………………………..64

Figure 26: Soil pore-water salinity and elevation of the plots where *Potentila anserina* was present……………………………………………………………………………….65

Figure 27: Kendall's correlation analysis of *Salicornia virginica* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta…………67

Figure 28: Seasonal growth patterns of *Salicornia virginica* across salinity and elevation gradients within the Nisqually Delta……………………………………………………..68

Figure 29: Soil pore-water salinity and elevation of the plots where *Salicornia virginica* was present……………………………………………………………………………….69

Figure 30: Kendall's correlation analysis of *Spergularia sp.* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta……………...70

Figure 31: Seasonal growth patterns of *Spergularia sp.* across salinity and elevation gradients within the Nisqually Delta…………………………………………………..71

Figure 32: Soil pore-water salinity and elevation of the plots where *Spergularia sp.* was present……………………………………………………………………………………72

Figure 33: Kendall's correlation analysis of *Triglochin maritimum* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta…………73

Figure 34: Seasonal growth patterns of *Triglochin maritimum* across salinity and elevation gradients within the Nisqually Delta………………………………………..74

Figure 35: Soil pore-water salinity and elevation of the plots where *Triglochin maritimum* was present……………………………………………………………………………….75

Figure 36: Species richness versus soil pore-water salinity…………………………...78

Figure 37: Species richness versus elevation…………………………………………….79

Figure 38: Pore-water salinity and elevation ranges of the study sites on the Nisqually National Wildlife Refuge in 2010…………………………………………………..81

Figure 39: Elevation of the Nisqually Delta based on a 2011 LIDAR flown by Watershed Sciences……………………………………………………………………………..84

List of Tables:

Table 1: List of all species encountered on the 2010 surveys……………………………35

Table 2: Salinity and elevation values for the nine species correlation analysis………...39

Table 3: Salinity and elevation tolerance ranges according to a literature review by Hutchison (1988), and the result of this research in the Nisqually estuary……………...76

Acknowledgments:

I would like to thank all the people who made this research possible: Kelley Turner for her knowledge, support, and guidance through this entire thesis project as well as her persistent yet gentle reminders of my deadlines, the field crew and volunteers for their help and dedication, Gerardo Chin-Leo for his thoughtful and timely edits of my drafts, his excellent ideas and encouragement, and his patience with my delayed drafts, Isa woo, Jean Takekawa, and Jesse Barham for their multiple reviews and thoughtful feedback, my family and friends for listening to my long discussions about my studies, and especially my children for all your love, interest, and support. I could not have done this without you.

1. INTRODUCTION

<u>1.1 *Research Significance and Project Summary*</u>

Estuaries are semi-enclosed coastal bodies of water where seawater is measurably diluted by freshwater drainage (Cameron and Pritchard 1963). These areas are some of the most productive and sensitive landscapes on Earth (USFWS 2004; Adam 1990). They support many species of plants and animals, protect inland areas from flooding, filter sediments, nutrients and pollution, as well as provide economic, recreational, and aesthetic value (Kruckeberg 1991; Scavia et al. 2002; USFWS 2004). Estuaries provide abundant food resources and sanctuary for resident and migratory birds; many commercially valuable fish species rely on estuaries as nursery grounds while they build biomass and acclimate to the salty water of the sea (Smith et al. 2000).

Many of these important habitats have been degraded or destroyed over the last 150 years. Currently, eighty percent of historic estuarine habitats in the Puget Sound region have been destroyed or severely degraded (USFWS 2004; Dean et al. 2001). Human influences such as damming of rivers, pollution, and development continue to degrade the physical condition and resilience of estuaries; leaving them vulnerable to additional impacts (Apostel and Sinclair 2006; Adam 1990). To reverse this trend, it is essential to conserve, restore, and protect these valuable habitats.

Even though many estuaries in the Pacific Northwest have been impacted by human activities since the 1800's, some are still rather unaltered and are ideal study sites for understanding how these ecosystems function (Thom et al. 2003). The Nisqually River, though degraded, is one of Washington’s least developed major river systems; making it a prime candidate for restoration. According to Apostol and Sinclair (2006), “an important first step in developing a restoration plan is linking valued resources (i.e., important plants and animals or wetland functions) with the factors hypothesized to control these factors.”

Estuaries are tidally influenced landscapes affected by changing salt concentrations and varying periods of inundation as the tides ebb and flow. Understanding how salinity and inundation influence salt marsh vegetation is important for developing restoration and adaptive management goals. Depth and duration of inundation has direct influence on salt marsh vegetation composition and density (Adam 1990). Several studies (Bertness et al. 1992; Boumans et al. 2002; and Hinkle and Mitsch 2005) have shown that vegetation communities can change dramatically along elevation and salinity gradients.

The Nisqually Delta can be categorized into four major habitat types; estuarine (including mudflat and salt marsh), freshwater wetland, riparian, and forested upland. This thesis will focus on the estuarine habitat of the Nisqually Delta and in particular, the vegetated intertidal areas which are known as salt marsh habitats. It will contribute to estuarine restoration science by examining the conditions that can result in successful establishment of salt marsh vegetation. Specifically, the role of pore-water salinity and inundation in determining the vegetation growth patterns of nine dominant species found throughout the Nisqually estuary, including the Nisqually National Wildlife Refuge, located in Washington State (Figure 1). By studying salinity and inundation in relation to salt marsh vegetation growth, land managers will have a fuller understanding of the requirements necessary to restore or establish salt marsh habitat. This research can be used to estimate the type and locations at which salt marsh vegetation may colonize the recently restored estuarine environment on the Nisqually National Wildlife Refuge.

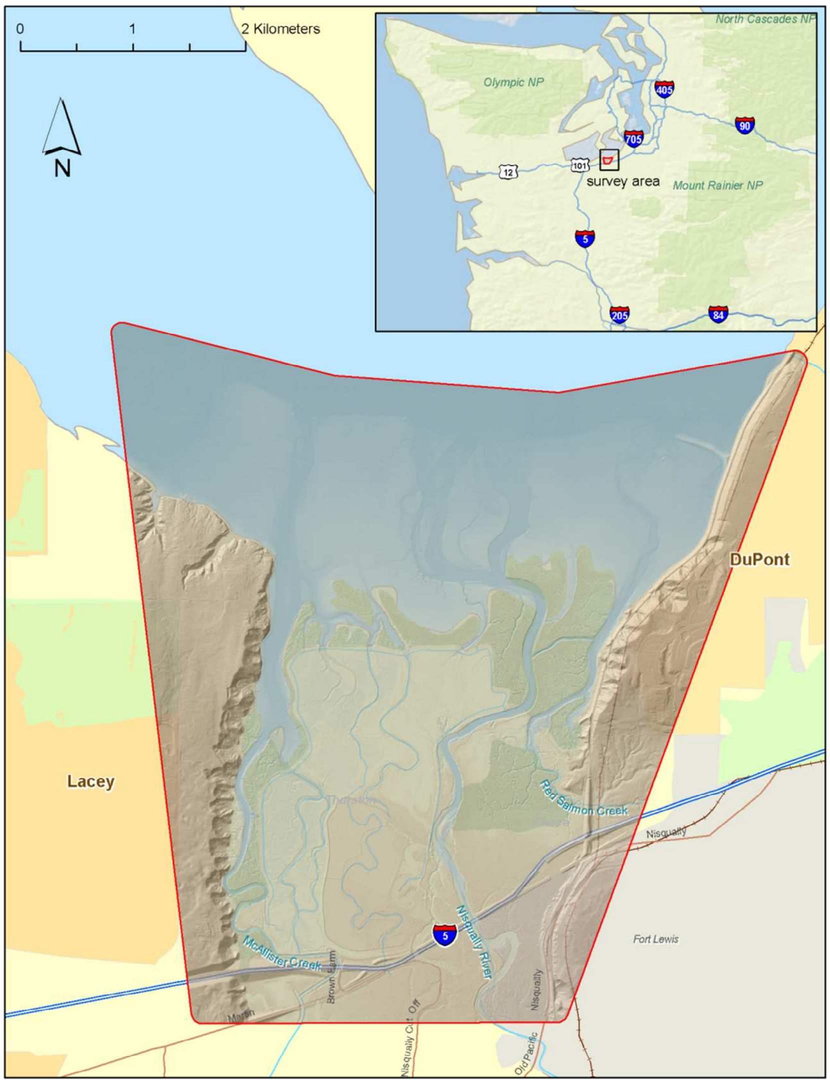


Figure 1: Location of the Nisqually estuary in Washington State.

1.2 ***Nisqually River History***

The Nisqually Delta was formed about 13,000-18,000 years ago from the retreat of the glaciers in the last ice age (Kruckeberg 1991). As the Puget Lobe glaciers receded they carved some of the waterways we know today as Puget Sound, Nisqually River, and McAllister Creek. In addition to the glacier retreat, the subduction of the Pacific Plate, as it collided with North America, helped shape the landscape of Puget Sound by forming mountains and valleys (Kruckeberg 1991). The rapid fill of sediment and the isostatic rebound as the last glacier retreated has kept the Puget Sound trough at about sea-level for the last several thousand years (Kruckeberg 1991).

The Nisqually River flows 78 miles from the Nisqually Glacier at Mount Rainier to the southern edge of Puget Sound to form the Nisqually Delta (Pierce County Public Works & Utilities; Kruckeberg 1991). The Nisqually River Basin is approximately 760 square miles (Pierce County Public Works & Utilities; Kruckeberg 1991). The Nisqually River passes through lands that are used in different ways, and has varied ownership including Mt. Rainier National Park, state parks, timberlands, hydropower projects, farmland, the Nisqually Indian Reservation, Fort Lewis, and the Nisqually National Wildlife Refuge (USFWS 2004). It also encompasses a multitude of habitats from old growth forests in Mt. Rainier National Park to glacial outwash lowland prairies, and finally to the tidal mudflats and estuarine habitat of the delta (Pierce County Public Works & Utilities).

The Nisqually Basin receives an average annual rainfall of 33-50 inches (83-127 cm) in the lowlands while the higher elevations receive more than 70 inches (177 cm) (Pierce

County Public Works & Utilities). The mouth of the Nisqually River mixes with the waters of Puget Sound thus creating the estuarine environment of the Nisqually Delta. The tidal regime in the Puget Sound is very distinct and dramatic; it has two high and two low tides, differing in size every day (semi-diurnal mixed tide regime) and the difference between the maximum yearly high and the minimum yearly low is approximately 20 feet or ~6 m (http://tidesandcurrents.noaa.gov/).

The people of Nisqually came from the Great Basin to settle in the Nisqually watershed thousands of years ago and were known as the Squalli-absch, which translates to, "people of the river and the grass" (http://www.nisqually-nsn.gov/). Once the Nisqually people had crossed the Cascade Mountain range one of their first major settlements was constructed on the Mashel River, which is a tributary of the Nisqually River. The Nisqually people lived off the Nisqually River, Puget Sound, and the local grasslands (prairies). They harvested fish, shellfish, crabs, oysters, and other seafood from the river and Puget Sound, and harvested berries and tubers (mainly camas) from the surrounding grasslands (Kruckeberg 1991, http://www.nisqually-nsn.gov/).

1.3 *Recent Nisqually Delta History*

Over the last century, tidal restriction, agriculture, and cattle grazing have degraded the historic estuarine condition of the Nisqually Delta. The first settlers to file a claim to the land west of the Nisqually River arrived in 1854, and in 1873 a Northern Pacific Railroad executive purchased the claim. The land was later sold to Alson Lennon Brown in 1904 (Nielsen 1980). Even though he only owned the land for 15 years, Brown is the most well known previous owner of the Delta because he purchased so much land, constructed a five mile dike to keep out the tides of Puget Sound, and created one of the area's biggest agricultural farms (Nielsen 1980). After Brown lost the land in 1919 it was leased to various agricultural enterprises over the next 55 years (Nielsen 1980). One of the primary uses of the land was a dairy farm.

The continuous grazing of cattle can have many detrimental affects to a landscape. The removal of vegetation alone causes degradation of the soils by limiting organic matter. The vegetation and soil is further damaged by trampling, and the animal waste disturbs the nutrient cycles as well as decreasing water quality (Goble and Hirt 1999). However, the farming practices in the Nisqually Delta were relatively low impact, leaving many of the historic tidal channel beds still intact within the diked areas.

In the 1960's the Delta was threatened with further development because of the proximity to urban centers (USFWS 2004). Local citizens initiated a grass roots movement to protect the Delta from development into a port through organized meetings and letters to the city, county, and state politicians (USFWS 2004). Development was stopped mostly due to a land purchase of the northern portion of the Nisqually Delta by the WDFW in 1966-67 (USFWS 2004). The Nisqually Delta was designated a National Natural Landmark by the Department of Interior in 1971 (USFWS 2004). In 1972, the Nisqually River Task Force, initiated by dedicated citizens, recommended that the delta be set aside as wildlife habitat, and in 1974 the United States government purchased the land and established it as a National Wildlife Refuge (USFWS 2004).

In the mid 1800’s Joel Meyers purchased a large amount of property in the Nisqually Delta east of the Nisqually River. This property was sold to Olie O. Braget who, in 1905, built a dike to create farming and grazing land for his cattle (Clemmens 2002). This land was used for grazing habitat for almost 100 years with continued alterations (levees and drainage ditches) through the mid 1900’s.

The Nisqually Tribe purchased the land in 2000, and in 2002 began a phased estuarine restoration program which has restored approximately 140 acres of salt marsh by reconnecting the hay fields to tidal flow (USFWS 2004; Ellings 2008; Wiltermood 2008). In 2005, the Nisqually Indian Tribe and Nisqually NWR signed a Cooperative Agreement, which authorized the Refuge to manage the tribal lowlands as part of the Refuge with provisions which enabled the Tribe to proceed with habitat restoration.

In the year 2000 a three phase restoration project was planned for portions of the diked lowlands within the 310 acre Braget farm (Wiltermood 2008). In 2002 the first phase began with the removal of dikes along the east and south portions of a 39 acre parcel (Phase 1; Figure 2) on the north end of the Braget Marsh (Wiltermood 2008). In 2006 the second phase (Phase 2) began with the return of tidal influence to the largest portion of the Braget Marsh restoration project; approximately 150 acres, 100 acres of salt marsh and 50 acres of riparian habitat (Wiltermood 2008). The third phase took place in August of 2011.

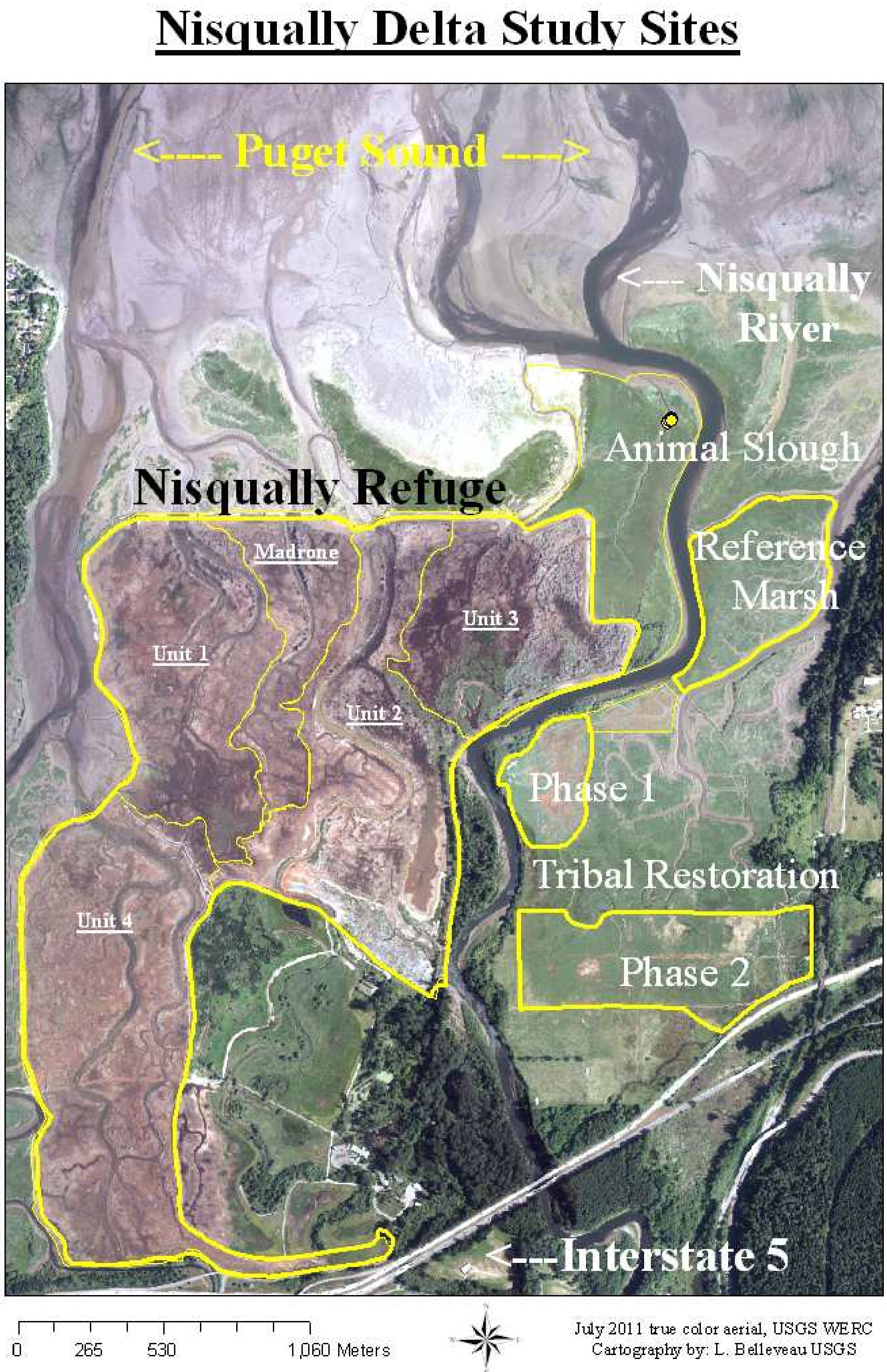


Figure 2: Outline of the four study locations within the Nisqually Delta used in this research, as well as the Nisqually National Wildlife Refuge restoration area.

1.4 *Management of the Nisqually Delta*

On Refuges, the land is managed for wildlife and habitat needs first and foremost. The goals of the Nisqually National Wildlife Refuge are given in detail in the Comprehensive Conservation Plan (USFWS 2004) and are to; “1) Conserve, manage, restore, and enhance native habitats and associated plant and wildlife species representative of the Puget Sound lowlands, with a special emphasis on migratory birds and salmonids, 2) Support recovery and protection efforts for Federal and State threatened and endangered species, species of concern, and their habitats, 3) Provide quality environmental education opportunities focusing on the fish, wildlife, and habitats of the Nisqually River delta and watershed, 4) Provide quality wildlife-dependent recreation, interpretation, and outreach opportunities to enhance public appreciation, understanding, and enjoyment of fish, wildlife, habitats, and cultural resources of the Nisqually River delta and watershed.”

Since the establishment of the Nisqually NWR in 1974, the land inside the five mile dike had been managed as freshwater wetland habitat. It took several years of planning and comments from public agencies, businesses, local governments, and private citizens before a preferred alternative was selected and funding secured to restore the Refuge lands to historical estuarine habitat. Many different restoration scenarios were examined for their effectiveness in fully restoring natural processes to the delta (USFWS 2004). The restoration alternative selected restores the most estuarine habitat (75% of historic), reconnects many of the historic slough channels creating a more functional estuarine system; while maintaining freshwater wetland and riparian habitats within the Refuge (USFWS 2004). This restoration will provide diverse habitats for many wildlife species, including migratory birds and threatened fish, as well as opportunities for the public to view active restoration and adaptive management, increasing their understanding of the restoring estuary and overall enjoyment of the Nisqually Delta (USFWS 2004).

Having a diversity of stakeholders can create challenges for managing the watershed. Scientific, technical, and policy experts must work together in a multidisciplinary manner in order to balance the desires and interests of all the stakeholders with the knowledge and needs of the ecosystem (Capobianco et al. 1998). Scientific research and monitoring is essential for supporting adaptive management. The Nisqually National Wildlife Refuge partnered with the Nisqually Indian Tribe and Ducks Unlimited to make restoration of the Nisqually Estuary possible. The monitoring of this restoration effort is an important contribution to our understanding of these complex ecosystems. The US Geological Survey in partnership with the Refuge and Nisqually Tribe is implementing the monitoring plan and evaluating habitat development and changes within this large scale restoration project (Ellings 2008, http://nisquallydeltarestoration.org/).

The Brown Farm dike was removed in 2009 allowing the historic tidal system to return to the landscape. The Nisqually National Wildlife Refuge restored 762 acres of estuarine habitat and enhanced 263 acres of freshwater wetland and riparian habitats within the Delta (USFWS 2004). In combination with the Nisqually Tribe's restoration projects on the east side of the river, over 900 acres of the Nisqually Delta are currently being restored making it the location of the largest estuary restoration project in the Pacific Northwest at this time (Ellings 2008). Restoration of the Nisqually Delta has the potential to expand critical habitat for threatened salmon species, migratory birds, as well as assist in the recovery of Puget Sound as a whole.

The research conducted for this thesis will add to our understanding of estuary restoration by examining the pore-water salinity, elevation, and vegetation present on both reference sites and recently restored sites. This information can be used to make predictions about the restoration site on the Nisqually National Wildlife Refuge, by comparing site conditions of the Refuge with the vegetation present at similar site conditions on the restoring sites.

1.5 *Salinity and its effects on vegetation growth*

Seawater is a mixture of salts comprised primarily of six ions: chloride (Cl^-), sodium (Na^+), sulfate (SO_4^{-2}), magnesium (Mg^{+2}), calcium (Ca^{+2}), and potassium (K^+) (Wildberger, 1993). Salinity is the amount (grams) of solid material dissolved in a kilogram of seawater and is expressed as parts per thousand (ppt) or practical salinity units (psu). For this research I used a refractometer to measure pore-water salinity in ppt.

Salinity has been shown to influence plant growth patterns, including salt marsh vegetation. High salinity concentrations within the soil can prevent germination and establishment of plants (Zedler 2001). Bertness et al. (1992) studied eight typical New

England high marsh species and in a controlled setting watered them with water of different salinities likely to be encountered in the marsh plain. They found that many of the species were significantly stunted in photosynthetic rate by higher salinities, with the exception of a few species (*Distichlis, Atriplex, and Aster*) that showed photosynthetic rates independent of the variations in salinity.

According to Adam (1990), salinity has adverse effects on plants because the levels of sodium and chloride can become toxic, thus interfering with nutrient uptake and lowering the external water potential. Interference with nutrient uptake can inhibit the plant's ability to create biomass thus limiting growth. A lowered external water potential is when the water outside of the plant cannot enter the plant during seawater inundation. This happens because of the differing ion concentrations between the external and internal water. In a tidally influenced landscape the salts of the water inundating the plant are much more concentrated than the internal water. Due to osmosis, the water inside of a plant submerged in salt water will flow out of the plant potentially leading to dehydration. Salt marsh plants surviving in this harsh environment must either exclude the salts at the roots or develop methods of excretion in order to maintain lower salinity within their cells (Hutchinson 1988, Adam 1990, Zedler 2001).

1.6 *Elevation and its effects on vegetation distribution*

In this research I have used measures of elevation as a proxy for inundation, with lower elevations having longer submergence time. Elevation has been established as a relative measurement of inundation, one of the driving factors of a tidally influenced landscape.

Roman, James-Pirri, and Heltshe (2001) noticed vegetation patterns on the New England marshes and attributed tidal inundation frequency and duration as the delineation between the high and low marsh. The low marsh being inundated twice daily and less frequent inundation as elevation increased. Boumans et al. (2002) defined low elevation marshes as being frequently flooded and high elevation marshes as occasionally flooded. Though this definition is rather vague, they were still able to identify that salt marsh vegetation species are distributed along a tidal gradient.

In the field guide "Wetland Plants of the Pacific Northwest" Weinmannn et al. (1984) describes marsh zonation patterns along a tidal gradient with eelgrass beds occurring below mean high water (MHW), low marsh occurring above MHW and high marsh occurring above mean higher high water (MHHW). In order to examine how marsh elevation influences the soil salinity of bare patches, Bertness et al. (1992) used days per month flooded to define 4 elevation ranges of (1) daily flooded, (2) 15 days per month, (3) 10 days per month, and (4) 5 days per month. Hinkle and Mitsch (2005) stated that elevations below mean high tide would support low marsh species, and in order to support high marsh species one should aim for elevations above MHW. For the purposes of this study the elevation of the MHW level was used to delineate between high and low marsh.

1.7 *Vegetation Studies of the Nisqually Delta*

Multiple studies have been conducted to characterize the vegetation at the Nisqually Delta. Mason et al. (1974) mapped the Refuge vegetation within the diked area and a narrow portion outside on the delta flats to the north. No elevation or salinity measurements were taken with this vegetation survey. On the delta flats they found an even distribution of *Distichlis spicata*, *Triglochin maritimum*, *Salicornia virginica*, *Jaumea carnosa* and *Carex spp*. The outermost reaches of the delta flats contained monoculture stands of *Distichlis spicata* as well as some pure stands of *Salicornia virginica*. They also found *Juncus spp.* species growing in circular patches as well as scattered throughout, *Grindelia integrifolia* along the slough edges and *Triglochin maritimum* as a constant member of the salt marsh community. The areas influenced by the Nisqually River, and thus influenced by freshwater, were dominated by *Carex spp.* in the lower areas and in higher areas the community was comprised of *Deschampsia cespitosa*, *Potentilla anserina spp. pacifica*, and *Triglochin maritimum*.

In 1975 Burg et al. conducted a study analyzing the above ground biomass at 138 quadrats within the undiked portions of the Delta in order to define the plant associations within the salt marsh (Burg et al. 1980). They identified a total of twelve plant associations on the Nisqually salt marsh. In the lower salt marsh areas they observed a dominance of *Spergularia marina*, *Salicornia virginica*, and *Distichlis spicata*, however, low areas closer to the Nisqually River were dominated by *Carex lyngbyei*. As they surveyed further up into the marsh plain they found communities with up to 15-16 different species with *Jaumea carnosa*, *D. spicata*, *Plantago maritimum*, *Triglochin maritimum*, *Grindelia integrifolia*, *Cuscuta salina*, and *Glaux maritimum* being the most dominant. In the higher marsh areas, *Deschamsia cespitosa*, *Juncus balticus* and *Festuca rubra* were observed. Burg et al. (1980) stated that on the Nisqually salt marsh salinity and elevation appear to be the two main environmental gradients influencing vegetation zonation patterns. They were able to state this because they identified that proximity to freshwater might be the determining factor for species presence or absence, while elevation determines the vertical distribution of species within these salinity boundaries.

In preparation for the Nisqually National Wildlife Refuge Comprehensive Conservation Plan Tanner et al. (2000) conducted a partial survey of elevations outside the diked area in order to determine more precise elevation distributions of certain plant communities. The rough estimations made by this limited study concluded that low marsh areas near the Nisqually River were dominated by *Carex lyngbei* and that areas away from freshwater influence were dramatically different with low marsh dominated by *Salicornia virginica*, and *Distichlis spicata* while the high marsh was dominated by *Deschampsia cespitosa*.

Clemmens (2002) conducted a vegetation study located on the Tribal property east of the Nisqually River. He found that *Carex lyngbei* dominated the lower portions of the channels and as the top of the channel banks were reached the community changed into a combination of *Distichlis spicata*, *Potentilla anserina spp. pacifica,* and *Atriplex patula*. The higher marsh contained *Scirpus* and *Juncus* dominated areas along with *Potentilla anserina spp. pacifica*, *Distichlis spicata* and *Jaumea carnosa*.

The Wiltermood (2008) reports based on the Nisqually Tribe's restoration projects concluded that Phase 1 (six years restored) was dominated by sand-spurry (*Spergularia*) and spikerush (*Eleocharis*) in the lower areas, while *Distichlis spicata* and *Jaumea carnosa* dominated the higher areas. The Phase 2 (two years restored) report findings concluded that some areas remained upland pasture, *Salicornia virginica* and *Spergularia* were the dominant species in the lower areas, while *Distichlis spicata* was dominant in both the high and low marsh areas.

1.8 *Vegetation Descriptions*

Based on the previous studies of the Nisqually Delta, I selected nine dominant species for an in-depth review. The nine species selected also cover a gradient of salinity tolerance levels ensuring that the effects of salinity and elevation were studied across a full range of plant salinity tolerance levels. The nine vegetation species nomenclature follows Hitchcock and Cronquist (1973) and are listed in alphabetical order: *Carex lyngbyei* (Lyngby's sedge), *Distichlis spicata* (seashore saltgrass), *Grindelia integrifolia* (entire-leaved gumweed), *Jaumea carnosa* (salt marsh daisy), *Juncus balticus* (Baltic rush), *Potentilla anserina* (silverweed), *Salicornia virginica* (pickleweed), *Spergularia sp.* (sand-spurry), and *Triglochin maritimum* (sea arrow-grass).

Below is a summary of the major characteristics of the dominant plant species considered in this study. Much of the current literature focused on only one species and those were mostly from East coast marshes which could be quite different from the species in the Pacific Northwest. For this reason an older paper was used to base salinity hypotheses on, (Hutchinson 1988), which reviewed several different publications covering salinity tolerance levels for many species from Pacific Northwest marshes. Elevation hypotheses for the species considered in this study were derived from Pacific Northwest specific plant identification books, (Weinmann et. al. 1984) & (Pojar and Mackinnon 1994), and a Nisqually specific study (Mason et al. 1974).

Carex lyngbyei (Lyngby's sedge) is a native, perennial found in areas of greater freshwater influence (Mason et al. 1974). It is commonly dominant along the inner delta sloughs in dense, often pure stands. This species is a true hydrophyte (loves water), and can be found in low and high marshes (Weinmann et. al. 1984). Hutchison (1988) reports that this species is not present when salinities reach above 20 ppt. Sedges are adapted to withstand inundation for long periods of time which allows it to survive at lower elevations, but it is found along the rivers edge because it is not able to withstand concentrated saline environments. *Carex lyngbyei* is an important brackish mudflat colonizer because the young plant provides a good source of protein for wildlife as well as promoting sedimentation as it grows (Pojar and Mackinnon 1994).

Distichlis spicata (seashore saltgrass) is a native, perennial grass of tidal marshes and seashores (Pojar and Mackinnon 1994). This grass can tolerate extremely high salinity by excreting excess salt through the pores in its leaves and can grow on the mudflats as well as in the high marsh (Mason et al. 1974). Hutchison (1988) reports that this species can withstand salinities greater than 50 ppt.

Grindelia integrifolia (entire-leaved gumweed) is a native, perennial aster that grows along beaches, rocky shores, and salt marshes (Pojar and Mackinnon 1994). It is most common in the high marsh and sometimes even in non-wetland locations (Weinmann et. al. 1984). Along with arrow grass (*Triglochin maritimum*), it is the tallest species in the salt marsh plain, and is found most often along slough edges (Mason et al. 1974). Hutchison (1988) reports that this species is found within salinities of less than 15 ppt.

Jaumea carnosa (salt marsh daisy) is a succulent, native, perennial aster, which is common on beaches, tidal mudflats, and marshes (Pojar and Mackinnon 1994). It is found in both high and low salt marsh (Weinmann et. al. 1984). Hutchison (1988) reports that has optimal growth at 9 ppt but is able to survive in salinities as high as 39 ppt.

Juncus balticus (baltic rush) is a perennial rush found in both brackish and saline marshes in the lower to mid elevations (Pojar and Mackinnon 1994). Juncus species have been reported to have 52% reductions in growth at salinities as low as 9 ppt, and 87% reduction at 17-29 ppt (Hutchison, 1988) However, *Juncus balticus* is one of the more salt tolerant of the rushes and may thrive at slightly higher salinities (Pojar and Mackinnon 1994, Weinmann et. al. 1984).

Potentilla anserina spp. pacifica (silverweed) is a native, perennial herb that is found most often in the high marsh meadows, at or above MHHW (Weinmann et. al. 1984, Hutchison 1988). Hutchison (1988) reports that this species is often found in salinity ranges of 0-12 ppt. This species is not restricted to estuarine habitats and can be found along stream edges as well as in the high salt marsh meadows (Pojar and Mackinnon 1994).

Salicornia virginica (pickleweed) is a native, fleshy perennial that is often found in the lower marsh where it gets inundated twice daily (Weinmann et. al. 1984). Mason et al. (1974) found this species in the higher marsh but in the areas where evaporation had concentrated the salinity. Hutchison (1988) states that this species has a salinity range of 20-80 ppt, which shows that it is a true halophyte and can handle, in fact flourish at high salinities.

Spergularia sp. (sand-spurry) is an annual species of the pink family, and is common on beaches, mudflats and marshes in either saline or brackish environments (Pojar and Mackinnon 1994). Spergularia is a pioneer species most often found in the low marsh and is adapted to withstand both high salinities and regular inundation (Weinmann et. al. 1984). Hutchison (1988) reports that this species is found within the salinity range of 6-20 ppt, and that it shows an increase of growth in brackish water versus fresh water; suggesting that it is a true halophyte and flourishes in moderate salinities.

Triglochin maritimum (sea arrow-grass) is a native, fleshy perennial herb and is often found in tidal marshes, mudflats, brackish meadows and sloughs (Pojar and Mackinnon 1994). This species is most commonly found in the low marsh where it is inundated twice daily, but occasionally found in the high marsh where it is inundated only once per day (Weinmann et. al. 1984). Mason et al. 1974 found this species to be a constant member of the salt marsh but never in high densities. Hutchison (1988) reports that *Triglochin* has variable growth in response to salinity and is found at salinities of 0-21 ppt.

1.9 *Research Question and Hypotheses*

My research question was, “How do salinity and inundation affect the growth, distribution and diversity of salt marsh vegetation?”

My hypotheses were:

- Salinity will be negatively correlated to species richness because high salinity environments are stressful areas for plant survival, thus fewer species will be present in the higher salinity environments.

- Elevation will be positively correlated to species richness because most species cannot handle long term inundation and so they seek refuge in the higher elevations, thus increasing the number of species present in the higher elevations.

- Salt marsh vegetation growth (cover, height and density) will differ along salinity and elevation gradients because salt marshes are tidally influenced landscapes where the stresses of high salinity and inundation are a daily occurrence, which will affect each species differently depending on their adaptations to these stresses.

Specifically, I expect *Distichlis spicata*, *Jaumea carnosa*, and *Salicornia virginica* to show a positive relationship with pore-water salinity, because they are adapted to tolerate the stress of higher salinity environments; and without the competition from other species they will be able to reach maximum growth. Since these species are found throughout the low and high marsh plain, I expect no significant relationship between these species and elevation. I expect that pore-water salinity will be the determining factor of their distribution because of their ability to withstand such high salinities.

I expect *Spergularia* and *Triglochin maritimum* to show a weak relationship with pore-water salinity, if any at all, because they are both adapted to medium salinity (15-25 ppt). I expect that these two species will show more of a salinity tolerance threshold; meaning that there will not be a clear linear relationship with growth and salinity, but rather an absence of these species from the plots with high (>25 ppt) pore-water salinities. These two species are both common to lower elevation areas; therefore, I expect that elevation will have a negative relationship on their distribution, because as elevation increases more species less tolerant of inundation may crowd them out and cause them to seek refuge in the lower elevations.

I expect *Carex lyngbyei*, *Grindelia integrifolia*, *Juncus balticus*, and *Potentilla anserina spp. pacifica* to show a negative relationship with pore-water salinity, because they are not adapted to tolerate the stress of saline environments, and as salinity increases it will have detrimental effects on their ability to grow. I expect elevation to have different relationships with these four species: *G. integrifolia* and *P. anserina* I expect to have a positive relationship with elevation, because neither species is common in the lower marsh where inundation is a regular occurrence. Both *G. integrifolia* and *P. anserina* are unable to withstand either high salinity or inundation; therefore I expect both pore-water salinity and elevation to be the determining factors of their distribution. *C. lyngbyei* is common in the lower marsh, and has adapted to withstand daily inundation; therefore, I expect that elevation will have a negative relationship with this species. *J. balticus* is common in the lower and mid elevations, so I expect no significant relationship between this species and elevation. However, both *C. lyngbyei* and *J. balticus* are not able to withstand high salinity, thus I expect salinity will be the determining factor in their distribution.

2. METHODS

2.1 *Study site*

This study was conducted on four different marshes throughout the Nisqually Delta, Washington, USA, 47.08°N 122.70°W (Figure 2). Two of the marshes, Phase 2 and Animal Slough, have significant freshwater inputs and thus represent brackish habitats. The other two marshes, Phase 1 and Reference, are primarily influenced by seawater and represent marine habitats. Pore-water salinity in the brackish sites varied from 2 to 26 ppt throughout the growing season (June-September 2010), and in the marine sites pore-water salinity varied from 15 to 45 ppt. The sampled substrate elevation within all four study sites varied from 2.08 to 3.08 m (NAVD88) for a total range of 1 m. One of each of the brackish (Phase 2) and marine (Phase 1) marshes were isolated from tidal influence and converted to agricultural lands in the early 1900's. They have recently been reintroduced to tidal influence; Phase 1 in 2002 and Phase 2 in 2006. The other brackish (Animal Slough) and marine (Reference Marsh) marshes serve as control sites because they have never been tidally restricted. The brackish sites contained a combination of vegetation typical of both fresh (*Typha* sp., *Carex* sp., and *Juncus* sp.) and salt marshes (*Triglochin maratimum*, *Potentilla anserina ssp. pacifica*, and *Distichlis spicata*) of the Pacific Northwest. The restored brackish marsh, Phase 2, still contains several pasture grass species. The marine sites contained vegetation typical of both high (*Deschampsia cespitosa*, *Hordeum* sp., and *Potentilla anserina ssp. pacifica*) and low (*Salicornia virginica*, *Jaumea carnosa*, and *Distichilis spicata*) salt marshes of the Pacific Northwest. The restored marine marsh, Phase 1, has much more bare ground in comparison to the control site.

2.2 *Survey methods*

2.2.1 *Vegetation*

A combination of seasonal and annual vegetation survey plots were used to inform this study. Both vegetation surveys were led by the U.S. Geological Society and the seasonal plots were part of a larger study looking at fish prey resources led by the Nisqually Indian Tribe. Field work was conducted by USGS biological technicians and volunteers. I was employed as one of the USGS technicians and assisted in the collection of all the data used in this thesis.

The goal of this research is to determine the possible relationship between vegetation parameters (percent cover, height, density, and species richness) and physical parameters (pore-water salinity and elevation). Measurements of salinity, elevation, and salt marsh vegetation characteristics were taken at 51 plots within brackish and marine marsh wetlands throughout the Nisqually Delta. Approximately thirty marsh species were observed and nine were selected for further analysis. The nine selected species were common in Pacific Northwest salt marshes and cover a range of salinity and inundation tolerances. Those nine species were: *Carex lyngbyei* (Lyngby's sedge), *Distichlis spicata* (seashore saltgrass), *Grindelia integrifolia* (entire-leaved gumweed), *Jaumea carnosa* (salt marsh daisy), *Juncus balticus* (Baltic rush), *Potentilla anserina* (silverweed), *Salicornia virginica* (pickleweed), *Spergularia sp.* (sand-spurry), and *Triglochin maritimum* (sea arrow-grass).

To quantify vegetation growth patterns over time, seasonal vegetation surveys were conducted at all sites from March to September of 2010. A total of 21 quarter meter quadrat plots were surveyed monthly over the growing season; 9 plots were established in the marine marsh sites (Reference n = 6, Phase 1 n = 3) and 12 plots were established in the brackish marsh sites (Animal Slough n = 6, Phase 2 n = 6). Roman, James-Pirri and Heltshe (2001) have shown that there is no significant difference in defining vegetation communities using 0.25, 0.5, 0.75 and 1 m^2 quadrats. Zedler (2001) states that a quarter meter quadrat proved suitable for salt marsh vegetation surveys. For the purposes of this study and time efficiency the smaller quadrat was used. Within each quadrat, percent cover, stem density, and maximum height were recorded monthly for each species present. Percent cover was determined using ocular estimation, where the observer stands over the quadrat and visually estimates the cover of each species present within the quadrat, stem density was determined by counting each individual plant rooted in the quadrat, and maximum height was measured using a measuring tape.

In August 2010, at the peak of the growing season, additional vegetation surveys were conducted. To capture environmental gradients, transects were placed perpendicular to channels within the study sites extending 50 meters into the marsh plain. Along each transect, using the point intercept method, the tallest species and height was recorded at 1 m intervals and 0.25 m^2 quadrat plots were placed and surveyed at 0, 20, and 40 m. According to Elzinga et al. (1998) point intercept combined with quadrat sampling is a good method for increasing the likelihood of capturing even the rare species. With the 21 seasonal plots surveyed monthly and the additional 30 plots along the transects surveyed in August, there was a total of 51 vegetation plots surveyed throughout the Nisqually Delta in the month of August 2010.

2.2.2 *Soil Pore-Water Salinity*

In estuaries, the input of freshwater as well as fine sediment and organic particles from rivers can complicate salinity measurements. To determine the exact composition of salts in water, complex methods such as titration are needed. For the purposes of this study, where the changes in concentration of total salts were more important, we chose to use a handheld NaCl refractometer (SPER SCIENTIFIC). This instrument is relatively inexpensive, requires no batteries and is easily transported into the field.

Pore-water salinity was measured by squeezing the pore-water from the substrate, through a coffee filter, onto the refractometer. In order to document species growth patterns over time in differing salinity ranges, pore-water salinity was measured monthly from June thru September 2010 in the 21 seasonal plots. Pore-water salinity was recorded in all 30 annual plots in August 2010 to document peak growth conditions in relation to salinity.

2.2.3 *Elevation*

Elevation at each quadrat and at every meter along each transect was determined using a Leica Viva CS-15 real time kinematic global positioning system (RTK-GPS). This instrument uses satellite and cellular communications with a reference station to receive real time elevation corrections at centimeter-level accuracy.

2.3 *Statistical analysis*

Descriptive statistics (mean and range values) were used to describe the pore-water salinity and elevation ranges for the species encountered in the surveys. For the elevation ranges, both quadrat and transect data were used. For the salinity ranges, only the quadrat data were used because salinity was not measured at every meter along transects.

For correlation analysis the August 2010 quadrat survey data were used for a total of 51 observations. Correlation analysis was conducted to explore the strength of linear dependence among the peak vegetation growth parameters (percent cover, height, and density) and the physical parameters (salinity and elevation). The data from these 51 plots did not meet the assumptions for parametric analysis, so Kendall's non-parametric correlation analysis was used (Kendall 1938).

The 21 plots measured monthly throughout the growing season of 2010 were analyzed by establishing salinity and elevation zones and investigating the growth patterns within these zones. The three salinity zones (low, medium and high) were chosen based on the greenhouse study conducted by Bertness et al. (1992) and the field studies of Crain et al. (2004). Bertness et al. (1992) used three salinity treatments in the greenhouse study; fresh (0 g/kg), brackish (15 g/kg), and saline (30 g/kg). Crain et al. (2004) found ranges within different marshes to be: fresh (0-10 ppt), brackish (15-25 ppt), and marshes exposed to seawater (27-33ppt). Using these two studies the salinity ranges were established as: low (<15 ppt), medium (15-25 ppt) and high (>25 ppt). For the 21 plots measured over the growing season of 2010 there were 5 low, 11 medium, and 5 high salinity plots.

The two elevation zones (high and low marsh) were established using the tidal datum from closest gauge station to the Nisqually Delta, the Dupont Wharf tide gauge station (http://tidesandcurrents.noaa.gov/). The data from this gauge station is based on an older tidal epoch; from observations collected in 1978. This tidal datum includes the relation between datum planes (tidal and land) and has been used by others (Tanner et al. 2000) on the Nisqually Delta to establish elevations in both a land datum (NAVD88) and a tidal datum format. Using this tidal datum, local water levels were identified in the land datum (NAVD88) as: mean lower low water (MLLW, -3.7 ft.), mean high water (MHW, 8.9 ft) and mean higher high water (MHHW, 9.8 ft). Then a simple conversion from feet to meters was done for comparison to the species elevation ranges identified in this study. The MLLW (-1.1 m) levels are inundated by even the lowest tides, MHW (2.7 m) is inundated twice daily by the average high tide and the MHHW (3 m) is inundated by only the high tides. In this study, elevation is used synonymously with inundation therefore the MHW was used for the level at which the low and high marshes were separated. Anything below MHW (2.7 m) is considered low marsh and anything above is high marsh.

A 2011 LIDAR raster (Watershed Sciences) was used in GIS to make an elevation map of the newly restored marsh at the Nisqually National Wildlife Refuge. In order to capture bare earth elevations, the LIDAR was flown at low tide in the winter of 2011 so that interference of water and vegetation would be minimized. Using the RTK-GPS elevation measurements collected at each sampling location, a local scale elevation range for each species encountered was created. Using the LIDAR data of the newly restored marsh plain along with the local scale species elevation ranges, elevations necessary for establishment of salt marsh plant communities can be identified; and estimations of likely plant type and cover can be made about the recently restored area.

3. RESULTS and DISCUSSION

3.1 *Soil pore-water salinity and elevation at the study sites*

This study was conducted on four marshes throughout the Nisqually Delta (Figure 3): Reference Marsh (REF), Phase 1 (P1), Phase 2 (P2), and Animal Slough (AS). The monitoring stations within the restoration area on the Nisqually National Wildlife Refuge (NNWR) were not used for the vegetation analysis because the recent tidal restoration activities will be the dominant factor determining vegetation presence on this landscape at this time. The four sites used in this study (REF, P1, P2, and AS) cover both the salinity and elevation gradients likely to be encountered on the newly restoring estuary within the Nisqually National Wildlife Refuge (Figure 4).

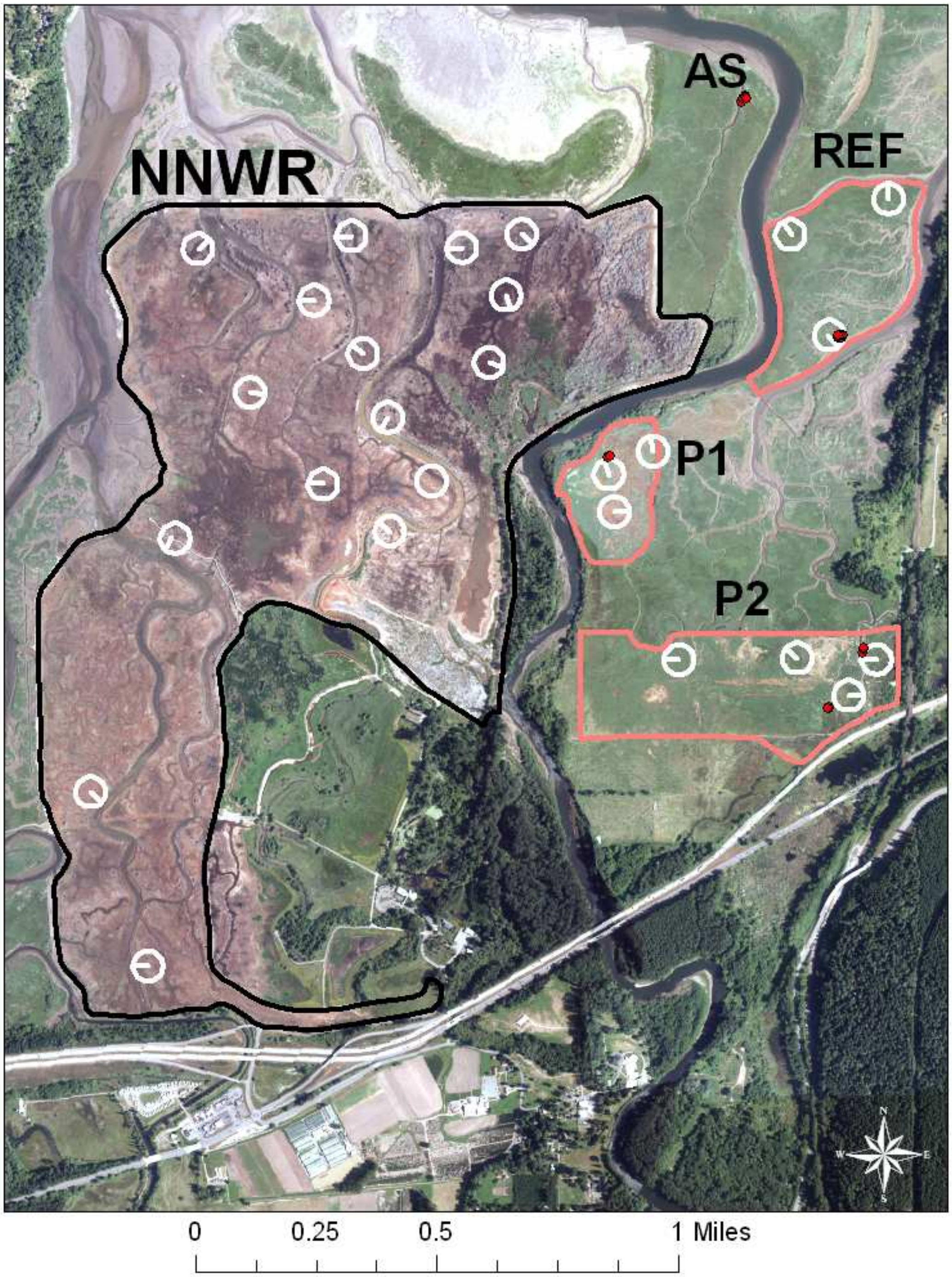


Figure 3: Monitoring locations within the Nisqually Delta. The white circles represent the annual vegetation transects, and the red dots represent the seasonal vegetation plots.

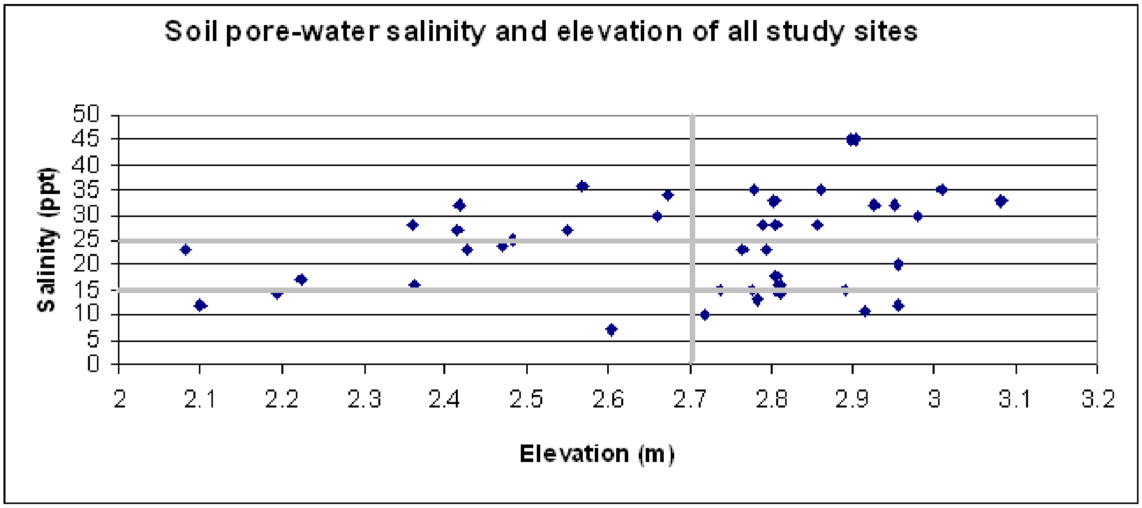
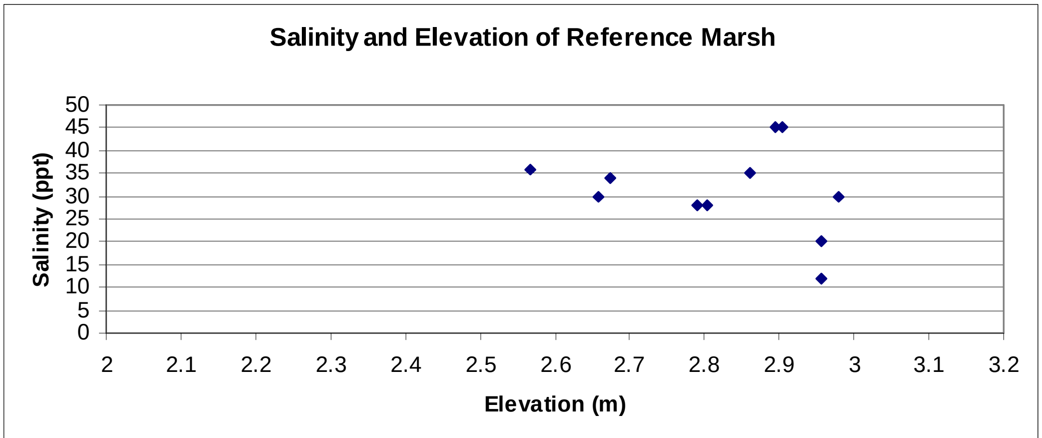


Figure 4: Salinity and elevation gradients of all four study sites (REF, P1, P2, and AS). Salinity values are taken from the 51 annual plots of August 2010; 8 plots were too dry to obtain a salinity value and are not plotted here. Outlined in grey horizontally are the salinity ranges of high (>25 ppt), medium (15-25 ppt), and low (<15 ppt). Outlined in grey vertically are the elevation zones of high (>2.7 m) and low (<2.7 m).

Based on the data collected in this research each of the four study sites had a different salinity and elevation range. These classifications are based on data gathered from the plots and may not be characteristic of the entire site. The marine sites, Reference and Phase 1, both were within the mid to high salinity ranges; with Reference in the higher elevations while Phase 1 is much lower (Figure 5). The brackish sites, Phase 2 and Animal Slough, were within the mid to lower salinity ranges; with Phase 2 in the higher elevations while Animal slough has both high and low elevations (Figure 6). This illustrates that the plot locations at each of the four study sites has differing characteristics that cover wide salinity and elevation gradients (Figure 4).

Marine Marshes

a.



b.

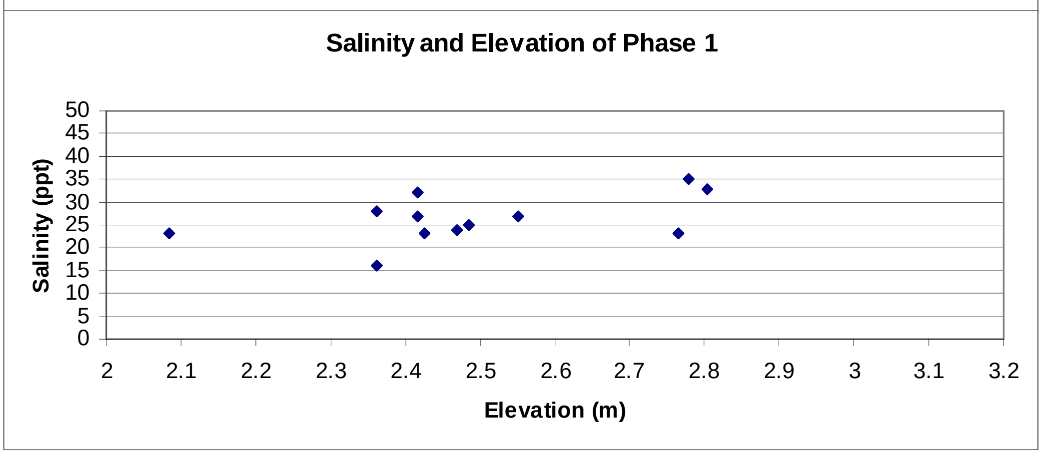


Figure 5 (a & b): August 2010 soil pore-water salinity and elevation of the plots located within the marine marshes. Both of these sites have salinity values in the mid to high ranges, with the exception of one plot with a value of 12 ppt. Reference Marsh (a) is the higher marine marsh with only 3 plots below 2.7 m elevation; while Phase 1 is the lower marine marsh with only 3 plots above 2.7 m elevation.

Brackish Marshes

a.

b.

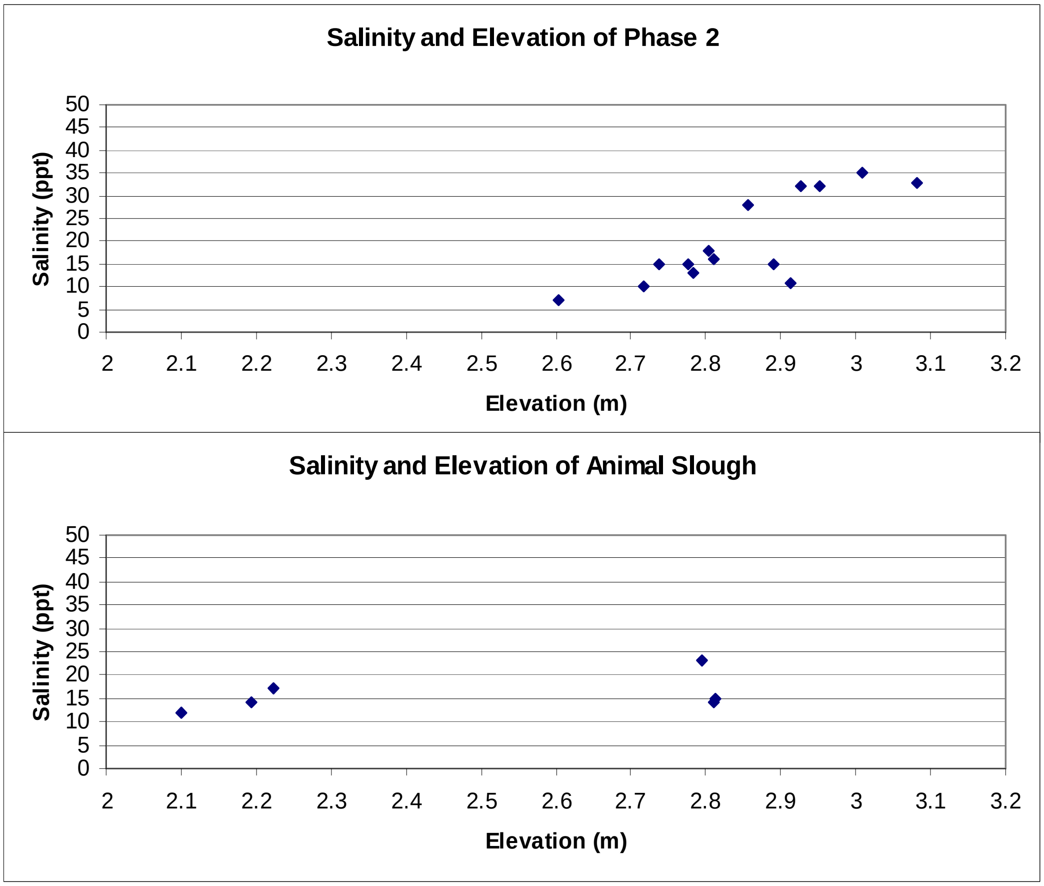


Figure 6 (a & b): August 2010 soil pore-water salinity and elevation of the plots located within the brackish marshes. Both of these sites have many salinity values in the mid to low ranges. Phase 2 (a) is the higher marine marsh with only 1 plot below 2.7 m elevation; while Animal Slough is the lower brackish marsh with 3 plots above 2.7 m elevation.

3.2 *Salinity Ranges of Nisqually salt marsh vegetation*

Salinity ranges were determined for every species encountered by using the salinity and vegetation data from all the quadrats, both seasonal and annual (Figure 7). The plot shows the ranges of salinity associated with the presence of a given species. Using the average salinity values for each of the species observed; six species (*Carex lyngbyei*, *Cotula coronopifolia*, *Hordeum brachyantherum*, *Juncus balticus*, *Lilaeopsis* *occidentalis*, and *Scirpus maritimus*) were found to occur in soils with low pore-water salinity (< 15 ppt), sixteen species (Brown algae, *Agrostis alba*, Green algae, *Atriplex patula*, *Distichlis spicata*, *Deschampsia cespitosa*, *Eleocharis acicularis*, *Elymus repens*, *Glaux maritimum*, *Hordeum jubatum*, *Jaumea carnosa*, *Potentilla anserina*, *Puccinellia nutkaensis*, *Salicornia virginica*, *Spergularia sp.*, and *Triglochin maritimum*) were found to occur in soils with medium pore-water salinity (15-25 ppt), and five species (*Cuscuta salina*, *Grindelia integrifolia*, *Plantago maritimum*, *Spergularia canadensis*, and *Stellaria humifusa*) were found to occur in soils with high pore-water salinity (> 25 ppt). Most of the species observed in the Nisqually Delta occurred in the brackish salinity range (15-25 ppt), and were observed in a large range of pore-water salinity values, indicating a tolerance of mid to high salinity for most Nisqually salt marsh species.

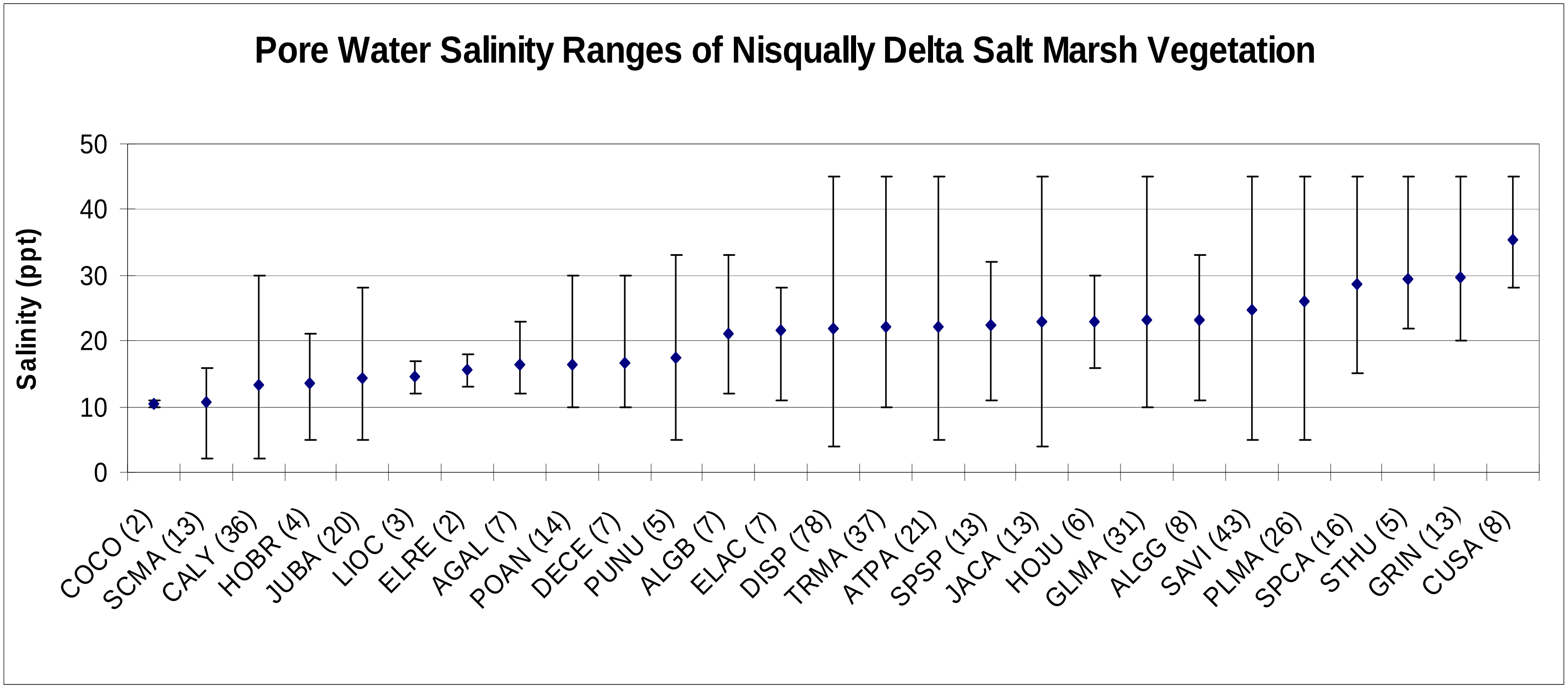


Figure 7: Soil pore-water salinity of all species observed on the Nisqually Delta in the vegetation surveys of 2010. This includes data from both the seasonal and annual surveys. The points represent mean values and the error bars represent the maximum and minimum salinity values which that species was encountered. Parentheses denote the number of observations; and the four letter species codes are listed in Table 1.

Table 1: List of all species encountered on the 2010 surveys.

Spp. Code	**Common Name**	***Scientific Name***
AGAL	Redtop	*Agrostis alba*
ALGB	Brown algae	*N/A*
ALGG	Green algae	*N/A*
ASSU	Douglas' aster	*Aster subspicatus*
ATPA	Patent saltbush	*Atriplex patula*
CALY	Lyngby's sedge	*Carex lyngbyei*
COCO	Brass buttons	*Cotula coronopifolia*
CUSA	Salt-marsh dodder	*Cuscuta salina*
DECE	Tufted hairgrass	*Deschampsia cespitosa*
DISP	Seashore saltgrass	*Distichlis spicata*
ELAC	Needle spikerush	*Eleocharis acicularis*
ELRE	Ryegrass	*Elymus repens*
GLMA	Sea milkwart	*Glaux maritimum*
GRIN	Entire-leaved gumweed	*Grindelia integrifolia*
HOBR	Meadow barley	*Hordeum brachyantherum*
HOJU	Foxtail barley	*Hordeum jubatum*
JACA	Salt marsh daisy	*Jaumea carnosa*
JUBA	Baltic rush	*Juncus balticus*
LACA	Canadian lettuce	*Lactuca canadensis*
LIOC	Western lilaeopsis	*Lilaeopsis occidentalis*
PLMA	Sea plantain	*Plantago maritimum*
POAN	Silverweed	*Potentilla anserina*
PUNU	Pacific alkali grass	*Puccinellia nutkaensis*
SAVI	Pickleweed	*Salicornia virginica*
SCMA	Seacoast bullrush	*Scirpus maritimus*
SPCA	Canadian sand-spurry	*Spergularia canadensis*
SPSP	Sand-spurry	*Spergularia sp.*
STHU	Salt-marsh chickweed	*Stellaria humifusa*
TRMA	Sea arrow-grass	*Triglochin maritimum*

3.3 *Elevation Ranges of Nisqually salt marsh vegetation*

Elevation ranges were determined for every species encountered by using the elevation and vegetation data from both quadrat and point intercept surveys along each transect (Figure 8). Using the average elevation values for each of the species observed, only four species' (Brown algae, Green algae, *Eleocharis acicularis*, and *Spergularia sp.*) average elevation occurred in low marsh (<2.71 m), while twenty four species' (*Agrostis alba*, *Aster subspicatus*, *Atriplex patula*, *Carex lyngbyei*, *Cotula coronopifolia*, *Cuscuta salina*, *Deschampsia cespitosa*, *Distichlis spicata*, *Elymus repens*, *Glaux maritimum*, *Grindelia integrifolia*, *Hordeum brachyantherum*, *Hordeum jubatum*, *Jaumea carnosa*, *Juncus balticus*, *Lactuca canadensis*, *Plantago maritimum*, *Potentilla anserina*, *Puccinellia nutkaensis*, *Salicornia virginica*, *Scirpus maritimus*, *Spergularia canadensis*, *Stellaria humifusa*, and *Triglochin maritimum*) average elevation occurred in high marsh (>2.71 m). Almost all of the species observed in the Nisqually estuary are distributed within the high marsh elevation. However, fifteen species (Brown algae, Green algae, *Atriplex patens*, *Carex lyngbyei*, *Cotula coronopifolia*, *Distichlis spicata*, *Eleocharis acicularis*, *Glaux maritimum*, *Hordeum brachyantherum*, *Jaumea carnosa*, *Salicornia virginica*, *Spergularia canadensis*, *Spergularia sp.*, and *Triglochin maritimum*) had elevation ranges that span both the high and low marsh, while the remaining thirteen species' (*Agrostis alba*, *Aster subspicatus*, *Cuscuta salina*, *Deschampsia cespitosa*, *Elymus repens*, *Grindelia integrifolia*, *Hordeum jubatum*, *Juncus balticus*, *Lactuca canadensis*, *Plantago maritimum*, *Potentilla anserina*, *Puccinellia nutkaensis*, *Scirpus maritimus*, and *Stellaria humifusa*) entire elevation range was confined to the high marsh (>2.71 m).

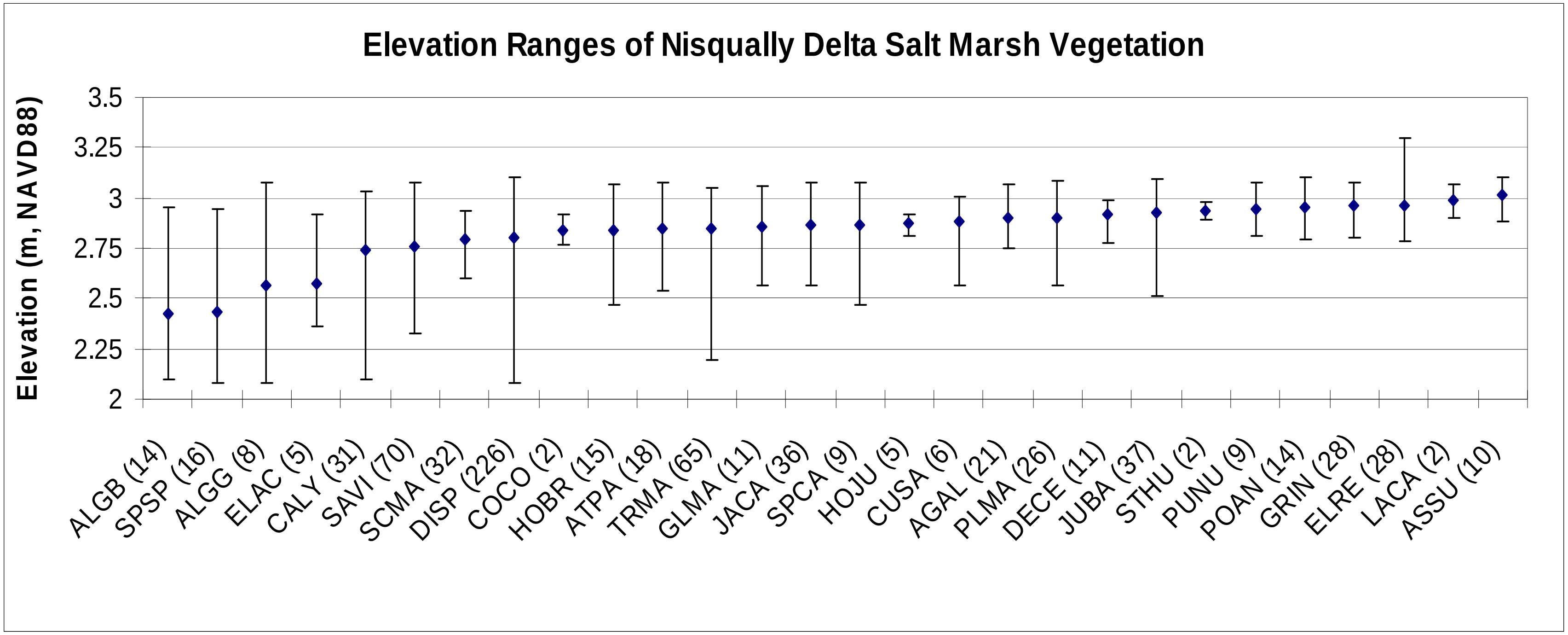


Figure 8: Elevation of all species observed on the Nisqually Delta in the vegetation surveys of 2010. This includes data from both the seasonal and annual surveys; including point intercept data. The points represent mean values and the error bars represent the maximum and minimum elevation values which that species was encountered. Parentheses denote the number of observations; and the four letter species codes are listed in Table 1.

3.4 ***Analysis of Vegetation Growth across Salinity and Elevation Gradients***

Pore-water salinity and elevation ranges were plotted for all species observed on the 2010 surveys, but only nine were selected for an in-depth analysis. These nine species were chosen based on their dominance in previous studies of the Nisqually Delta and their documented salinity tolerances. Species with tolerances from each zone (high, medium, and low salinity) were selected to ensure the affects of salinity and elevation were studied across a full range of plant salinity tolerance levels. The nine species chosen were: *Carex lyngbyei* (Lyngby's sedge), *Distichlis spicata* (seashore saltgrass), *Grindelia integrifolia* (entire-leaved gumweed), *Jaumea carnosa* (salt marsh daisy), *Juncus balticus* (Baltic rush), *Potentilla anserina* (silverweed), *Salicornia virginica* (pickleweed), *Spergularia sp.* (sand-spurry), and *Triglochin maritimum* (sea arrow-grass).

In order to examine the species-environment relationships correlation analysis was conducted using the 51 annual vegetation plots surveyed during the peak of the growing season in late July to early August of 2010. The data from the 51 plots did not meet the assumptions for parametric analysis, so Kendall's non-parametric correlation analysis was used (Kendall 1938). All possible combinations were tested which yielded 54 correlation scatter plots. For clarity, the results are summarized in Table 2. The scatter plots are included in the analysis and discussion of each species. Brief descriptions of the overall results are presented below.

Table 2: Salinity and elevation significance values for the nine species correlation analysis. The * indicates a statistically significant relationship (* p<0.1, ** p< 0.01, and *** p< 0.001). The +/- indicates a positive or negative relationship.

species	salinity	elevation
Carex lyngbyei % cover	*** -	-
Carex lyngbyei height	*** -	-
Carex lyngbyei density	*** -	-
Distichlis spicata % cover	** +	+
Distichlis spicata height	-	+
Distichlis spicata density	** +	+
Grindelia integrifolia % cover	* +	** +
Grindelia integrifolia height	* +	** +
Grindelia integrifolia density	* +	*** +
Jaumea carnosa % cover	** +	** +
Jaumea carnosa height	+	* +
Jaumea carnosa density	** +	** +
Juncus balticus % cover	* -	* +
Juncus balticus height	* -	** +
Juncus balticus density	* -	* +
Potentilla anserine % cover	-	** +
Potentilla anserine height	-	** +
Potentilla anserine density	-	** +
Salicornia virginica % cover	** +	+
Salicornia virginica height	* +	+
Salicornia virginica density	** +	+
Spergularia sp. % cover	* +	+
Spergularia sp. height	* +	+
Spergularia sp. density	* +	+
Triglochin maritimum % cover	+	* +
Triglochin maritimum height	-	* +
Triglochin maritimum density	+	* +

Of the 51 plots, 8 occurred in the low salinity range (<15 ppt), 15 in the medium (15-25 ppt), 20 in the high (>25 ppt), and 8 plots were too dry in August to get a salinity reading. The low elevation range (< MHW; 2.71 m) contained 16 of the 51 plots while the high marsh (>MHW; 2.71 m) contained the remaining 35 plots.

Increased pore-water salinity showed a negative relationship with three of the nine species (*Carex lyngbyei, Juncus balticus, and Potentilla anserina*) indicating that most species studied for this thesis are adapted to tolerate higher salinities (Table 2). Increased elevation showed a negative relationship with only one of the nine species (*Carex lyngbyei*) indicating that most species studied for this thesis are not adapted to tolerate long term inundation, and will most often be found in the higher marsh where they are inundated only once per day (Table 2).

Carex lyngbyei was negatively influenced by both pore-water salinity and elevation, with a highly significant influence by pore-water salinity indicating that salinity is the determining factor for this species' growth and distribution (Table 2). *Grindelia integrifolia* and *Potentilla anserina* were the two species most influenced (positive relationship) by elevation, indicating that submergence time is the determining factor for these species' growth and distribution (Table 2).

Overall, pore-water salinity and elevation both have a positive influence on the salt marsh vegetation species studied. These species can tolerate high salinities, but submergence time (i.e. elevation) may be the dominant factor explaining differences in growth and distribution. According to the results of this research many species have both salinity and elevation thresholds at which growth is stunted or the species become absent altogether. This threshold appears to be at 30 ppt for salinity and below 2 m for elevation.

When comparing the seasonal plots to the annual plots used in the correlation analysis, the salinity and elevation of the seasonal plots were also well distributed throughout both the salinity and elevation gradients. The seasonal analysis was done using the 21 plots that were surveyed monthly throughout the growing season (March – September) of 2010. Of the 21 plots, 5 occurred in the low salinity range (<15 ppt), 11 in the medium salinity range (15-25 ppt) and 5 in the high salinity range (>25 ppt); 8 of the 21 plots occurred in the low marsh (<MHW; 2.71 m) and 13 in the high marsh (>MHW).

Below are more detailed results for each of the nine species, including both the seasonal and annual survey analysis. Each point in the correlation scatter plot represents the presence of that species in a given plot and the points with a value of zero represents absence of that species for those plots.

3.4.1 *Carex lyngbyei*

For *Carex lyngbyei* pore-water salinity had significant negative relationships with percent cover, height, and density (p-values < 0.001; Table 2; Figure 9). The seasonal analysis of *Carex lyngbyei* reveals similar relationships; with an absence from every plot with high pore-water salinity and maximum growth reached in the plots with lowest pore-water salinity values suggesting that pore-water salinity is the limiting factor in the growth and distribution of this species (Figure 10). Density did not show a clear difference between the high and low elevations in the seasonal analysis, while percent cover and height reached maximum values in plots with lower elevations, suggesting the ability to withstand inundation (Figure 10). Although *Carex lyngbyei* was present in only 13 of the

51 annual plots and 9 of the 21 seasonal plots the results still indicate that it is not capable of withstanding high salinity environments, but may be capable of withstanding inundation or grow taller in lower elevations in order to reduce the inundation time (Figure 11). These data suggest that the presence of a tall, dense stands of *Carex lyngbyei* in the Nisqually estuary are likely to occur in a lower elevation area near a significant freshwater influence.

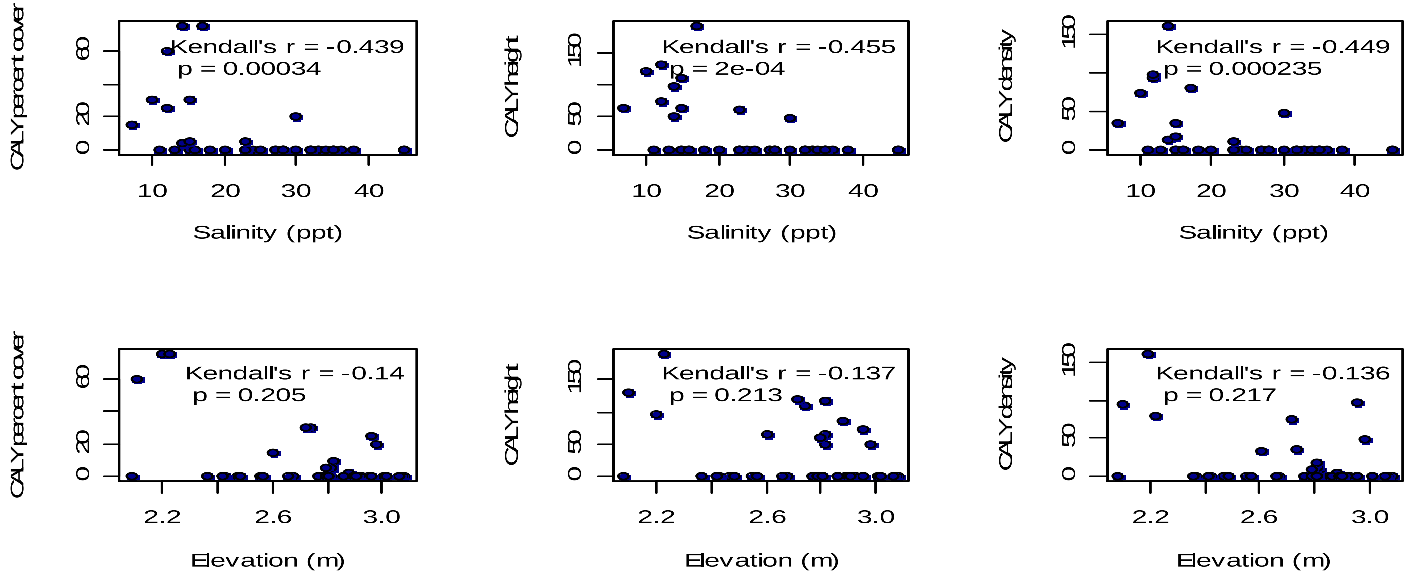


Figure 9: Kendall's correlation analysis of *Carex lyngbeyi* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

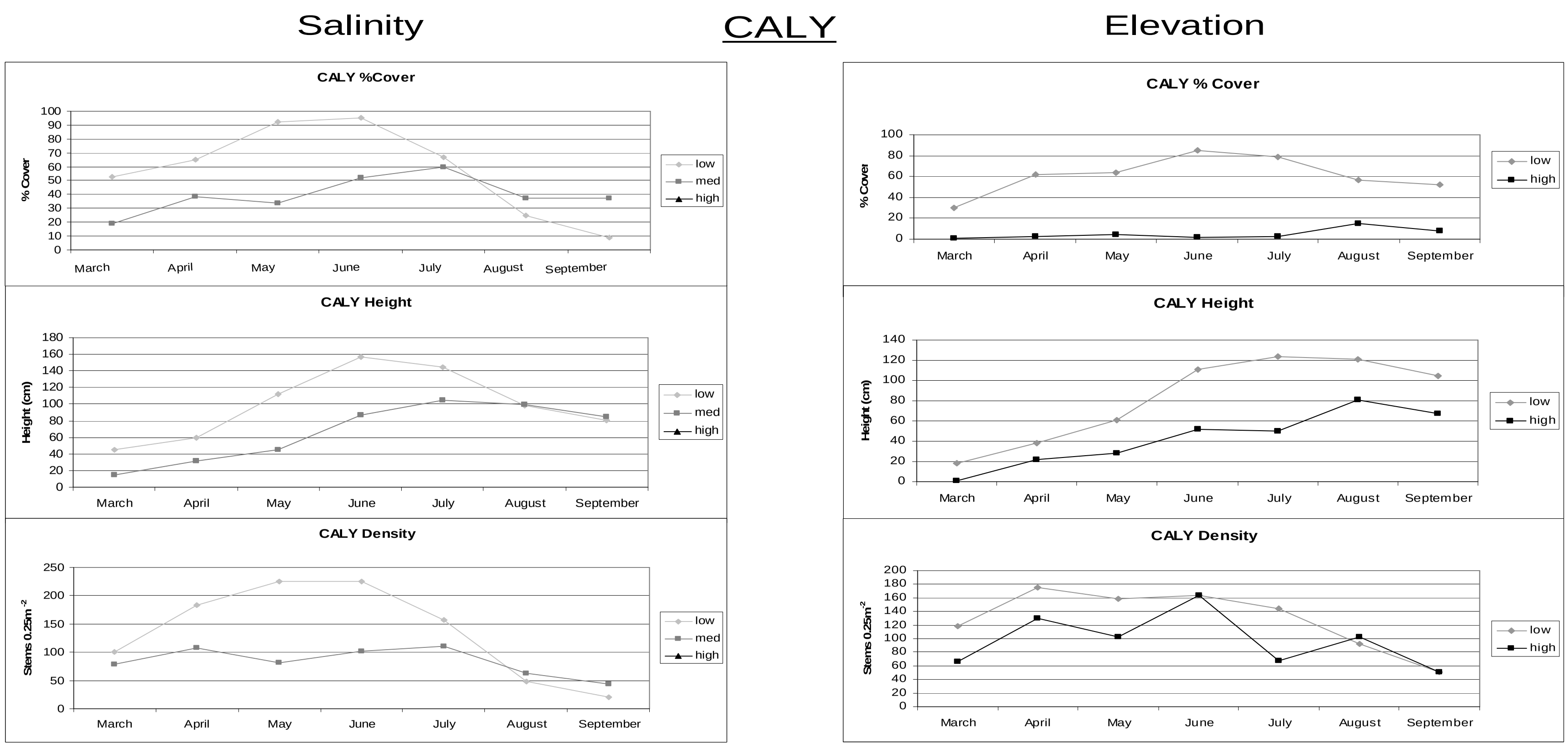


Figure 10: Seasonal growth patterns of *Carex lyngbyei* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

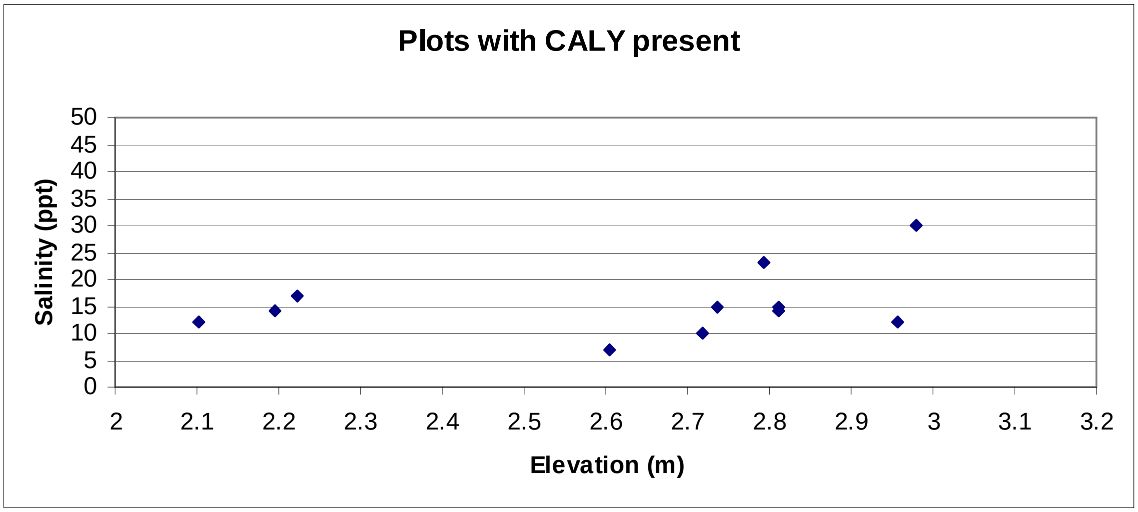


Figure 11: Soil pore-water salinity and elevation of the plots where *Carex lyngbyei* was present.

3.4.2 *Distichlis spicata*

For *Distichlis spicata* pore-water salinity had significant positive relationships with percent cover and density (p values < 0.01; Table 2; Figure 12). The seasonal analysis of *Distichlis spicata* reveals similar relationships; with maximum percent cover and density reached in the plots with highest pore-water salinity values (Figure 13). *Distichlis spicata*, however, grew 35 cm taller on average in low salinity areas (Figure 13). This height difference could be due to less energy expenditure on salt excretion and thus more energy available for height growth (Hutchinson, 1988). Elevation did not show a strong relationship with any of the growth metrics (percent cover, height and density) in either the correlation or seasonal analysis. *Distichlis spicata* was the most widespread species in the Nisqually Delta, with a presence in 38 of the 51 annual plots and 18 of the 21 seasonal plots; indicating that it is capable of withstanding the high salinity and inundation of salt marsh environments. These data suggest that *Distichlis spicata* is likely to be present at elevations above 2m throughout the Nisqually Estuary marsh plain, with increased presence in the higher salinity environments (Figure 14).

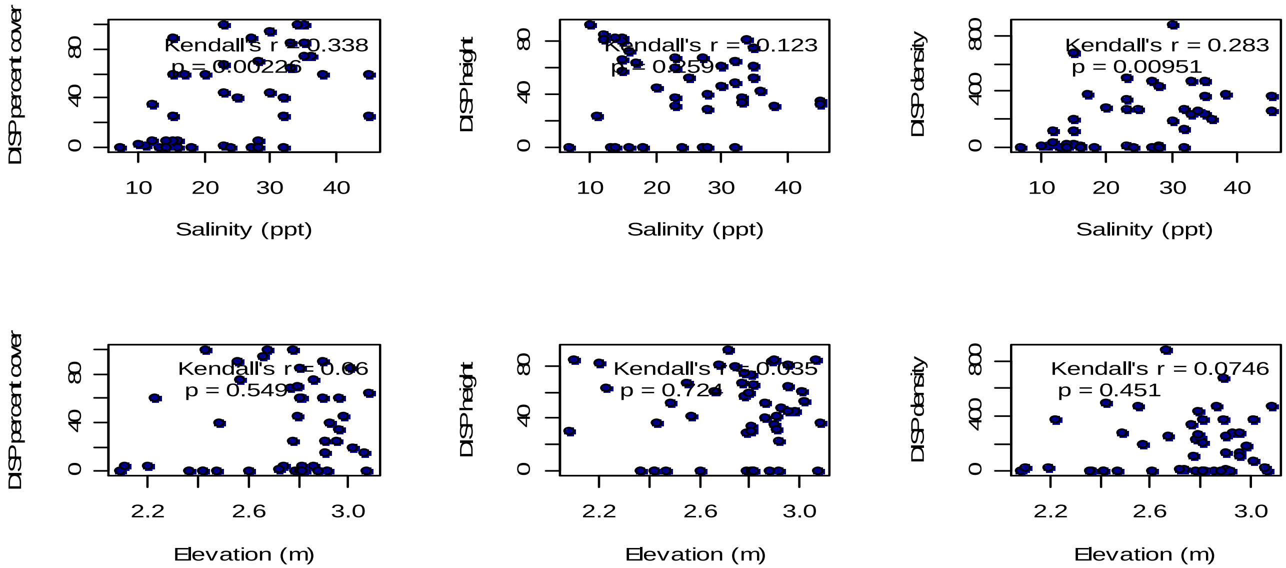


Figure 12: Kendall's correlation analysis of *Distichlis spicata* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

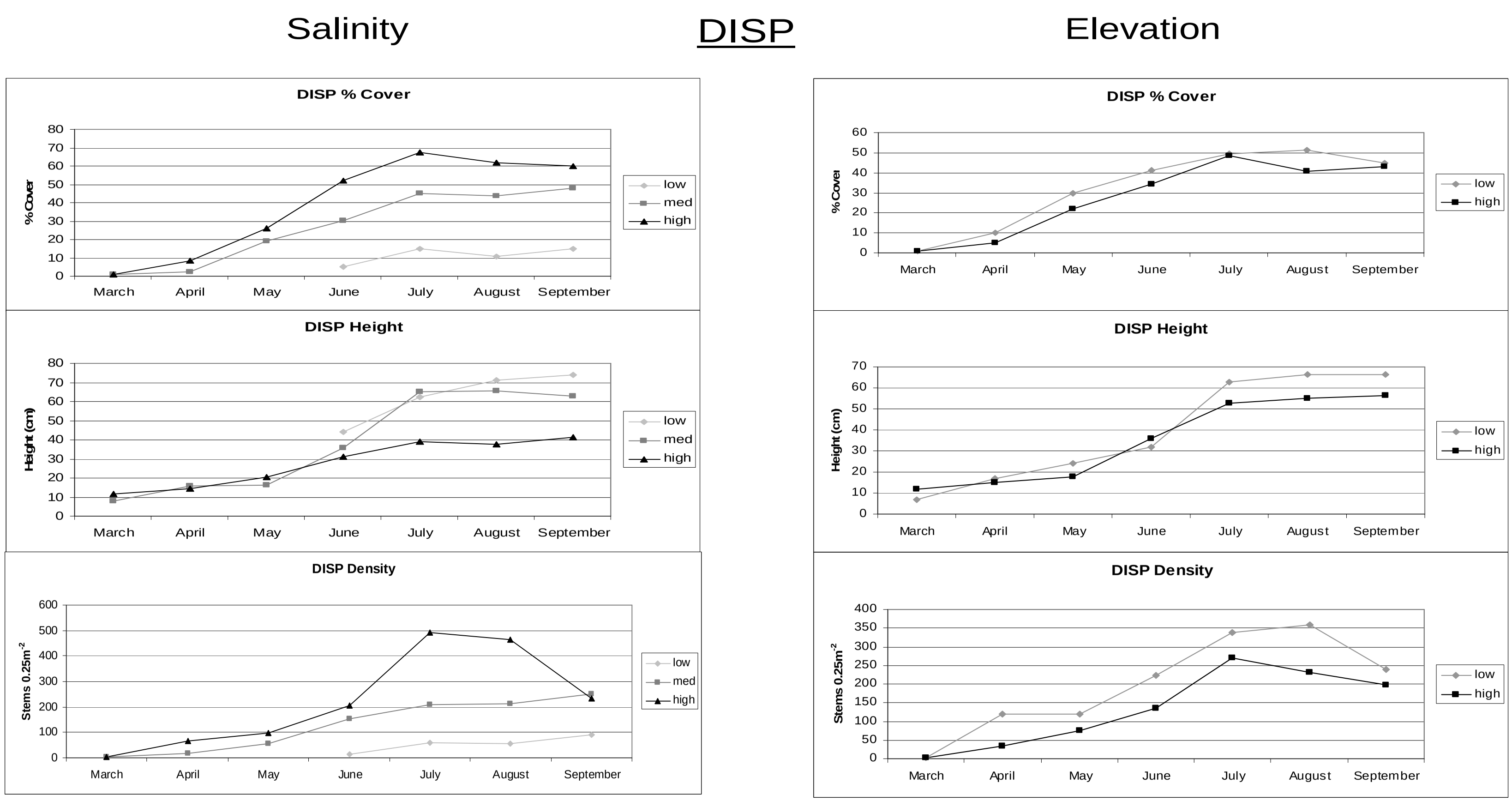


Figure 13: Seasonal growth patterns of *Distichlis spicata* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

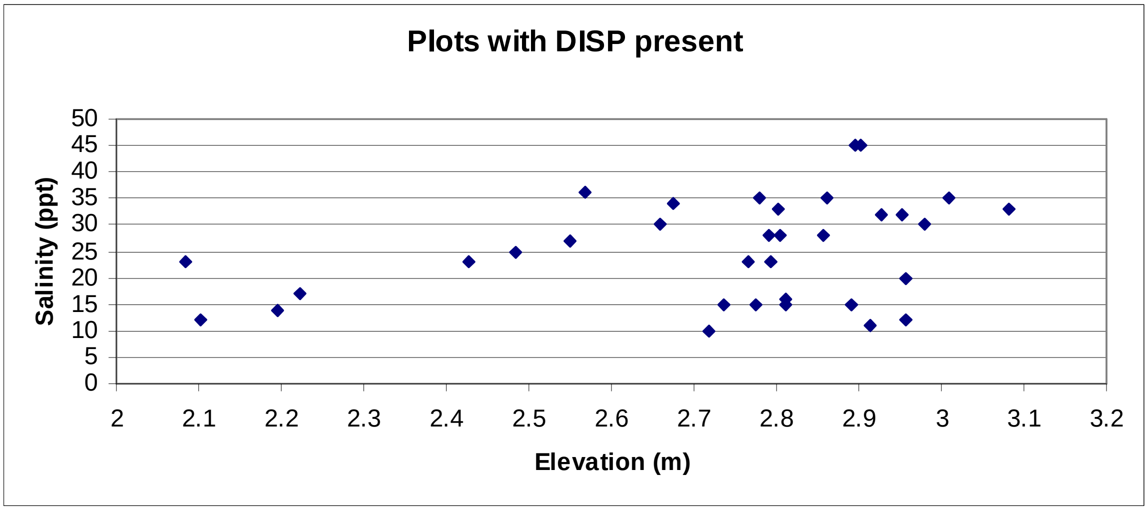


Figure 14: Soil pore-water salinity and elevation of the plots where *Distichlis spicata* was present.

3.4.3 *Grindelia integrifolia*

For *Grindelia integrifolia* both pore-water salinity and elevation showed significant positive relationships with percent cover, height, and density (p-values < 0.05; Table 2; Figure 15). However, elevation shows a much stronger relationship (p-values < 0.001; Table 2; Figure 15). The seasonal analysis of *Grindelia integrifolia* reveals similar relationships; with presence only detected in the mid to high salinity and high elevation areas (Figure 16). Although *Grindelia integrifolia* was present in only 8 of the 51 annual plots and 4 of the 21 seasonal plots the results still indicate that this species is capable of withstanding high salinity environments, but may not be adapted to withstand long term inundation (Figure 17). The results of this research show that *Grindelia integrifolia* was present only in salinities above 20 ppt, which is not consistent with the literature review by Hutchinson (1988) stating that *Grindelia integrifolia* is found at salinities below 15ppt. These data suggest that *Grindelia integrifolia* is likely to be present at higher elevation locations within the Nisqually estuary, with an increased presence in areas with brackish to high pore-water salinity. However, *Grindelia integrifolia* appeared in so few plots that the trends detected may not be representative of the entire population. More data on this species is needed to confirm these trends.

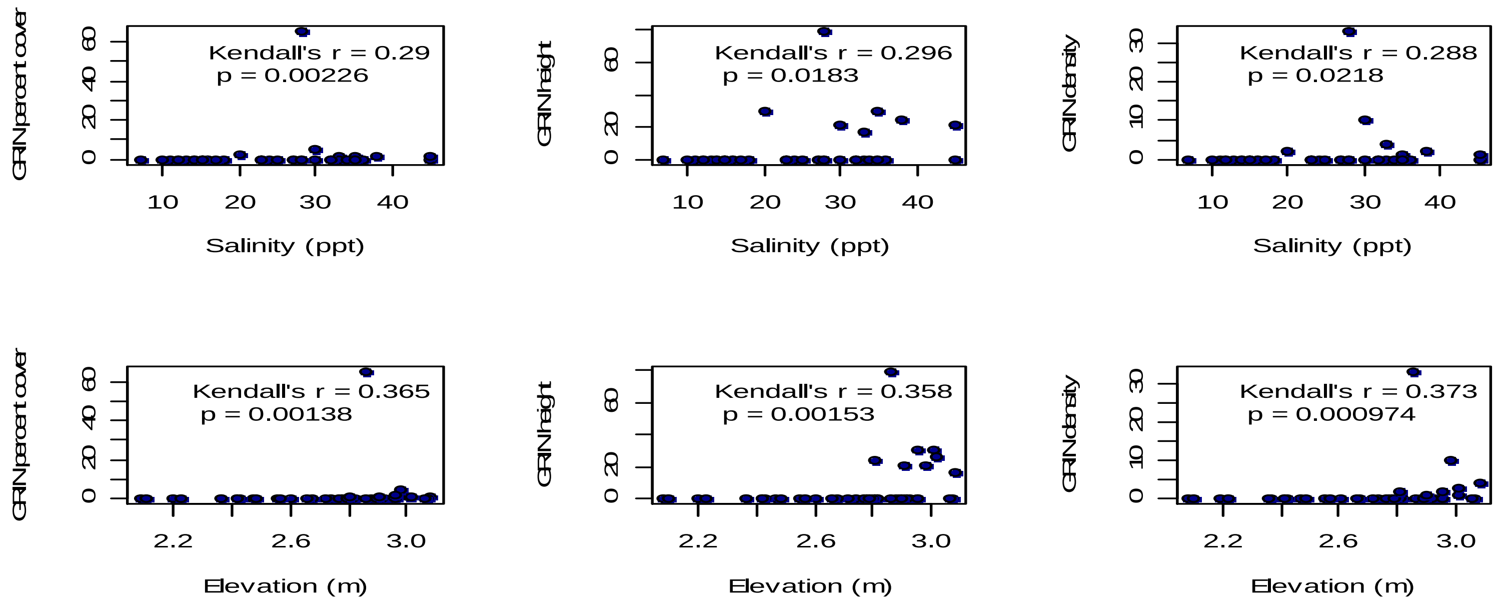


Figure 15: Kendall's correlation analysis of *Grindelia integrifolia* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

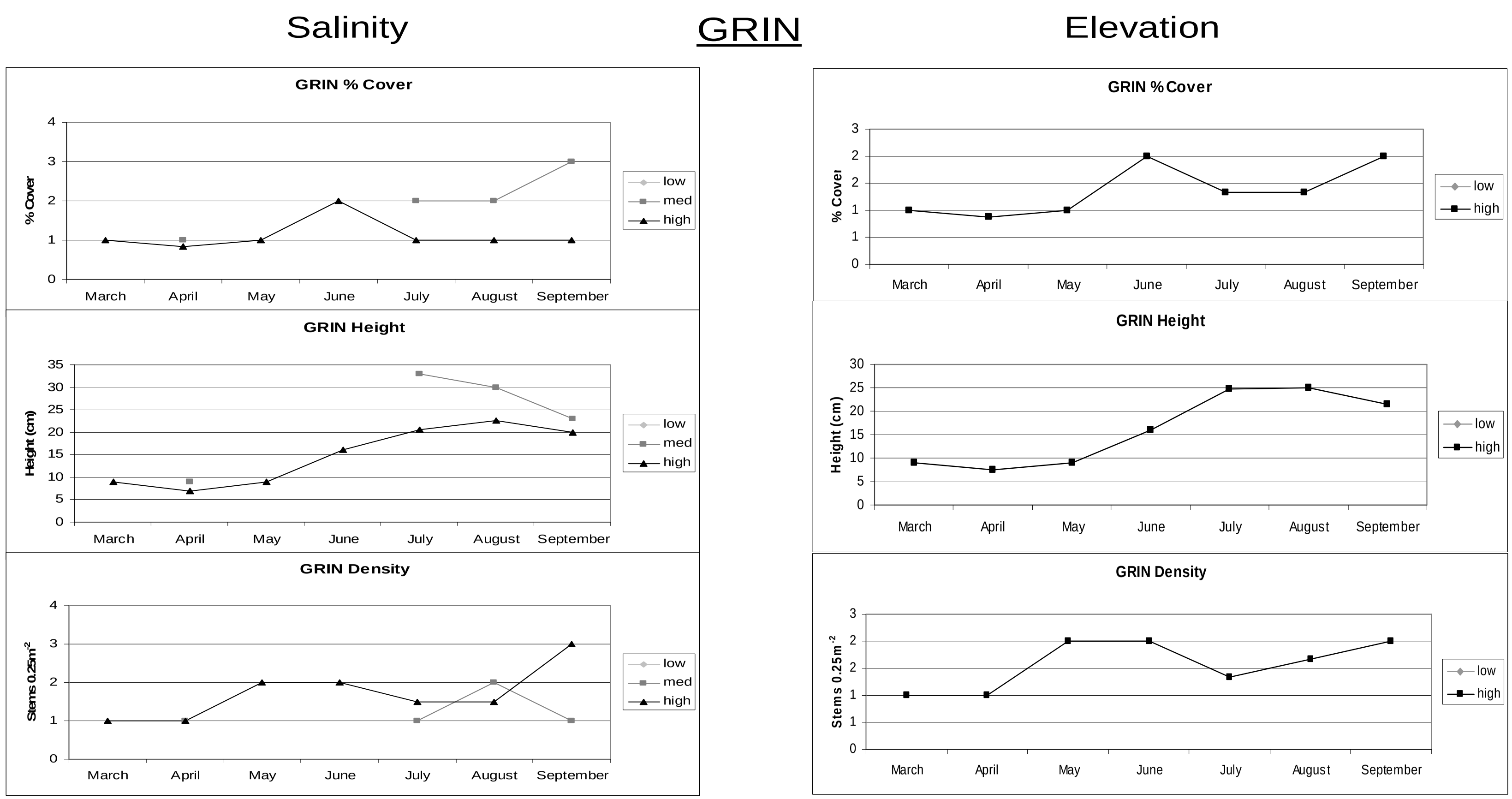


Figure 16: Seasonal growth patterns of *Grindelia integrefolia* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

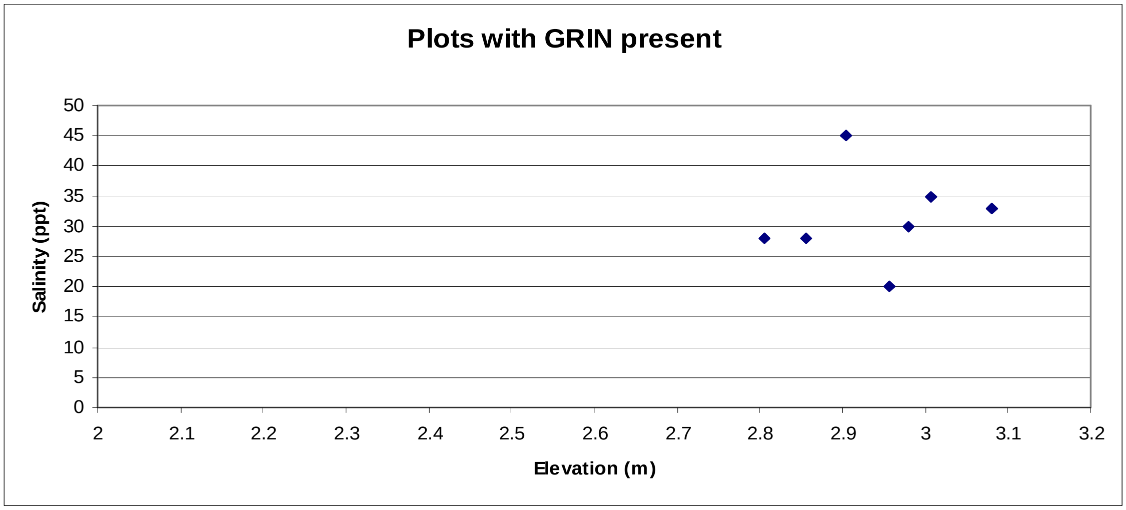


Figure 17: Soil pore-water salinity and elevation of the plots where *Grindelia integrefolia* was present.

3.4.4 *Jaumea carnosa*

For *Jaumea carnosa* both pore-water salinity and elevation showed significant positive relationships with percent cover and density (p-values < 0.05; Table 2; Figure 18). Height of *Jaumea carnosa* showed a significant relationship with elevation (p-value < 0.05), but not pore-water salinity (Table 2; Figure 18). The seasonal analysis of *Jaumea carnosa* reveals similar relationships; with maximum percent cover and density in the higher salinity and higher elevation areas; and height showing no discernable pattern among the soil pore-water salinity and elevation ranges (Figure 19). These results show that *Jaumea carnosa* has a wide pore-water salinity tolerance range, but not for elevation (Figure 20). This is not consistent with the literature review of Hutchinson (1988) stating that *Jaumea carnosa* has a wide range of salinity tolerance. *Jaumea carnosa* is, however, one of the most widespread species in the Nisqually Delta with presence in 27 of the 51 annual plots and 11 of the 21 seasonal plots. These data suggest that *Jaumea carnosa* is likely to be present at the higher elevation locations within the Nisqually estuary, with an increased presence in high elevation areas that have higher pore-water salinity.

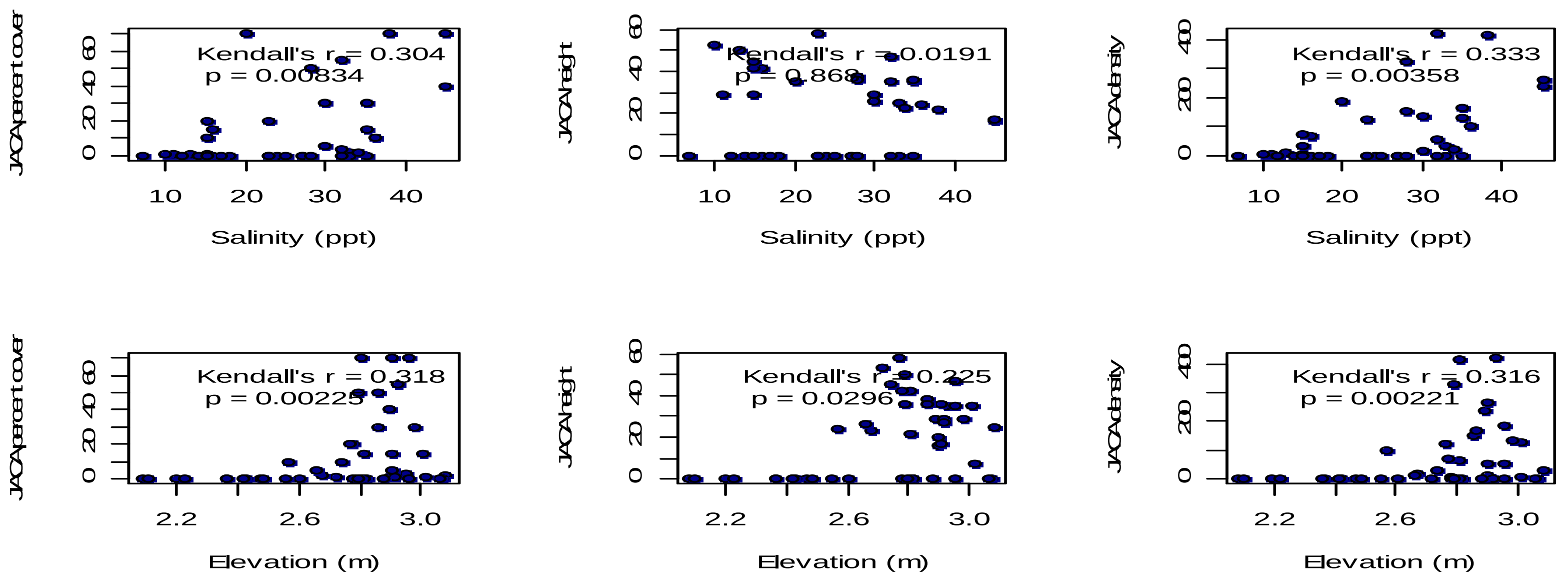


Figure 18: Kendall's correlation analysis of *Jaumea carnosa* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

Salinity JACA Elevation

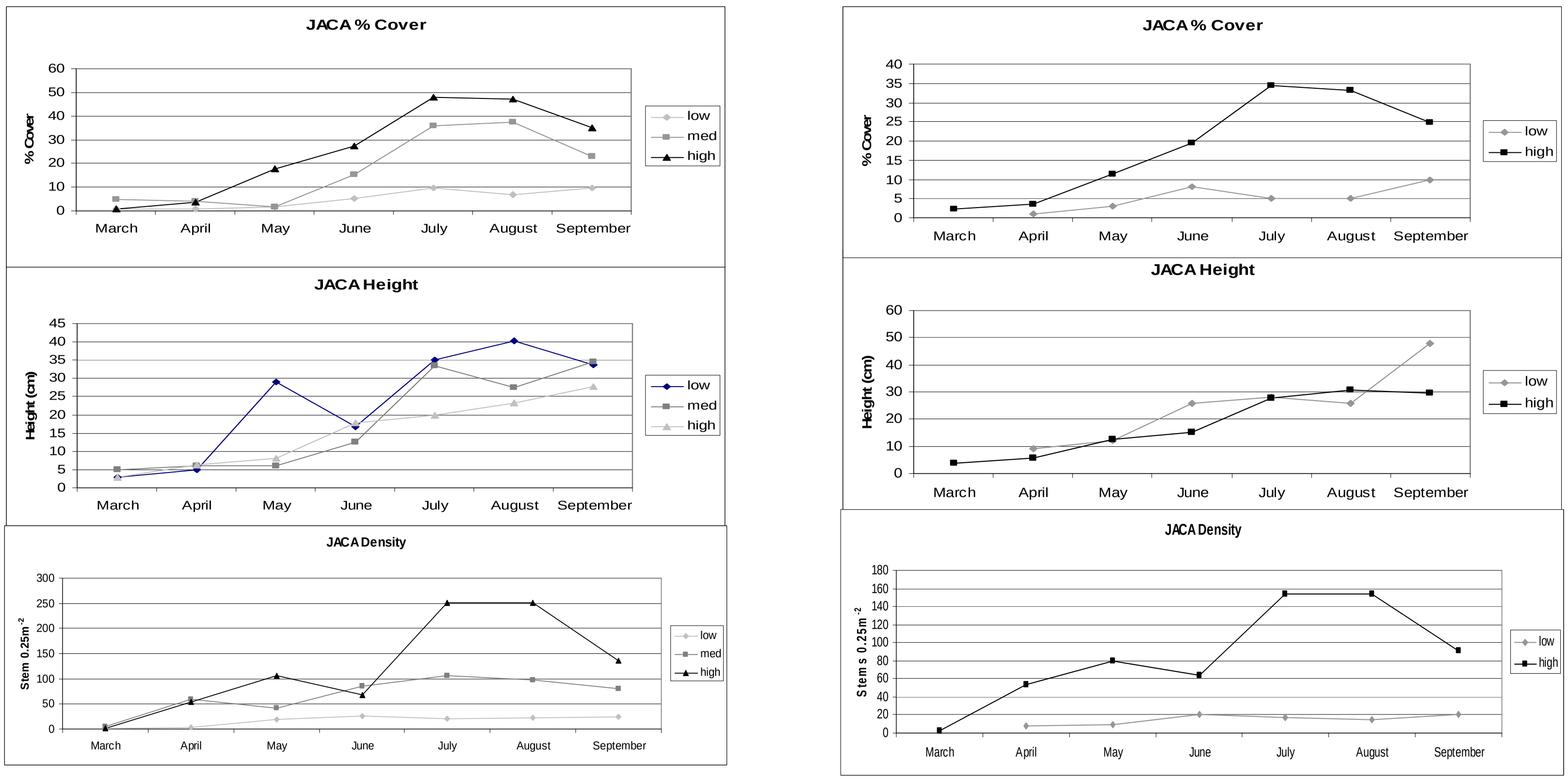


Figure 19: Seasonal growth patterns of *Jaumea carnosa* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

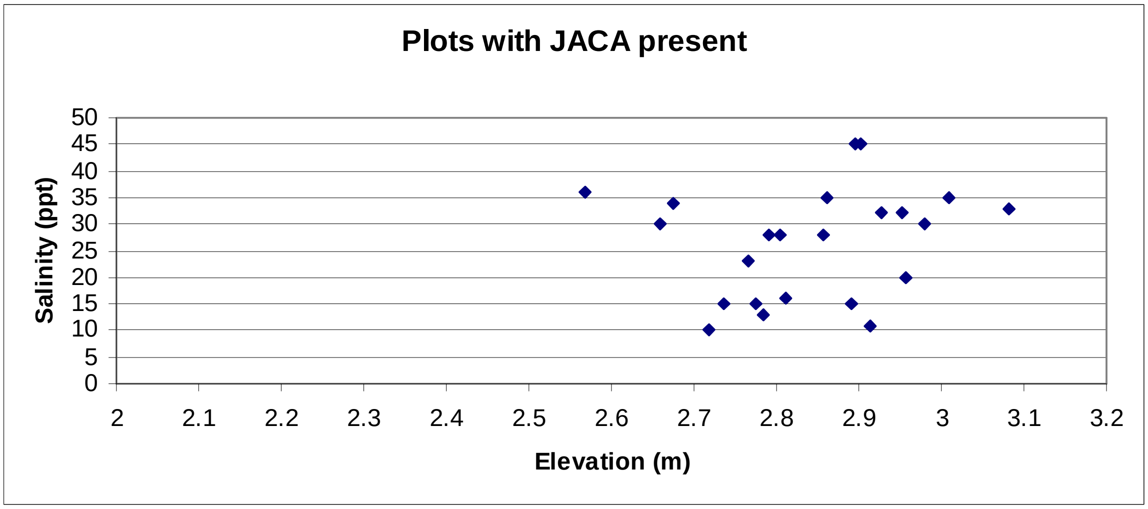


Figure 20: Soil pore-water salinity and elevation of the plots where *Jaumea carnosa* was present.

3.4.5 *Juncus balticus*

For *Juncus balticus* pore-water salinity showed a significant negative relationship with height (p-value < 0.05; Table 2; Figure 21). Pore-water salinity showed negative relationships with percent cover and density also, but not quite as strong a relationship (p-value < 0.1; Table 2; Figure 21). Elevation showed significant positive relationships with percent cover, height, and density of *Juncus balticus* (p-value < 0.05; Table 2; Figure 21). The seasonal analysis of *Juncus balticus* reveals similar relationships; with maximum percent cover and density in the low salinity and high elevation areas; presence was only detected in the mid to low salinity plots, and height showed no discernable pattern among the pore-water salinity and elevation ranges (Figure 22). Although *Juncus balticus* was present in only 10 of the 51 annual plots and 5 of the 21 seasonal plots the results still indicate a low tolerance of high salinity environments, and may not be adapted to withstand long term inundation either (Figure 23). These data suggest that *Juncus* *balticus* is likely to be present only at the locations within the Nisqually estuary that are at higher elevations with a significant freshwater influence.

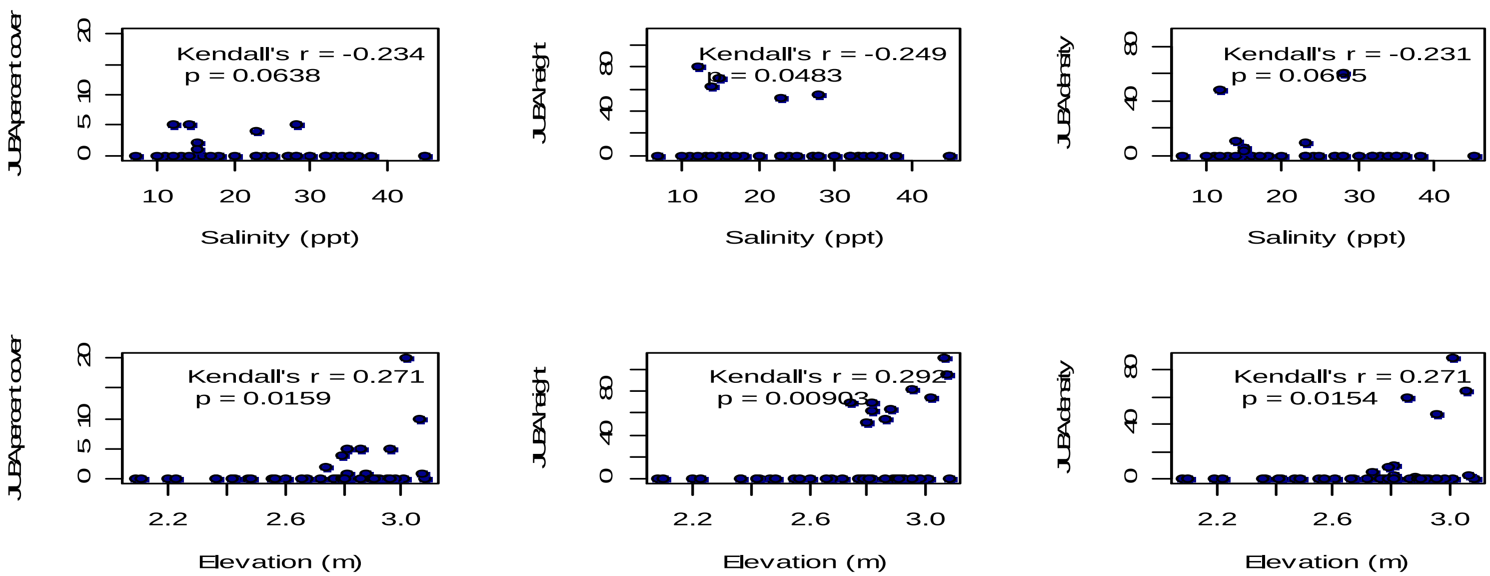


Figure 21: Kendall's correlation analysis of *Juncus balticus* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

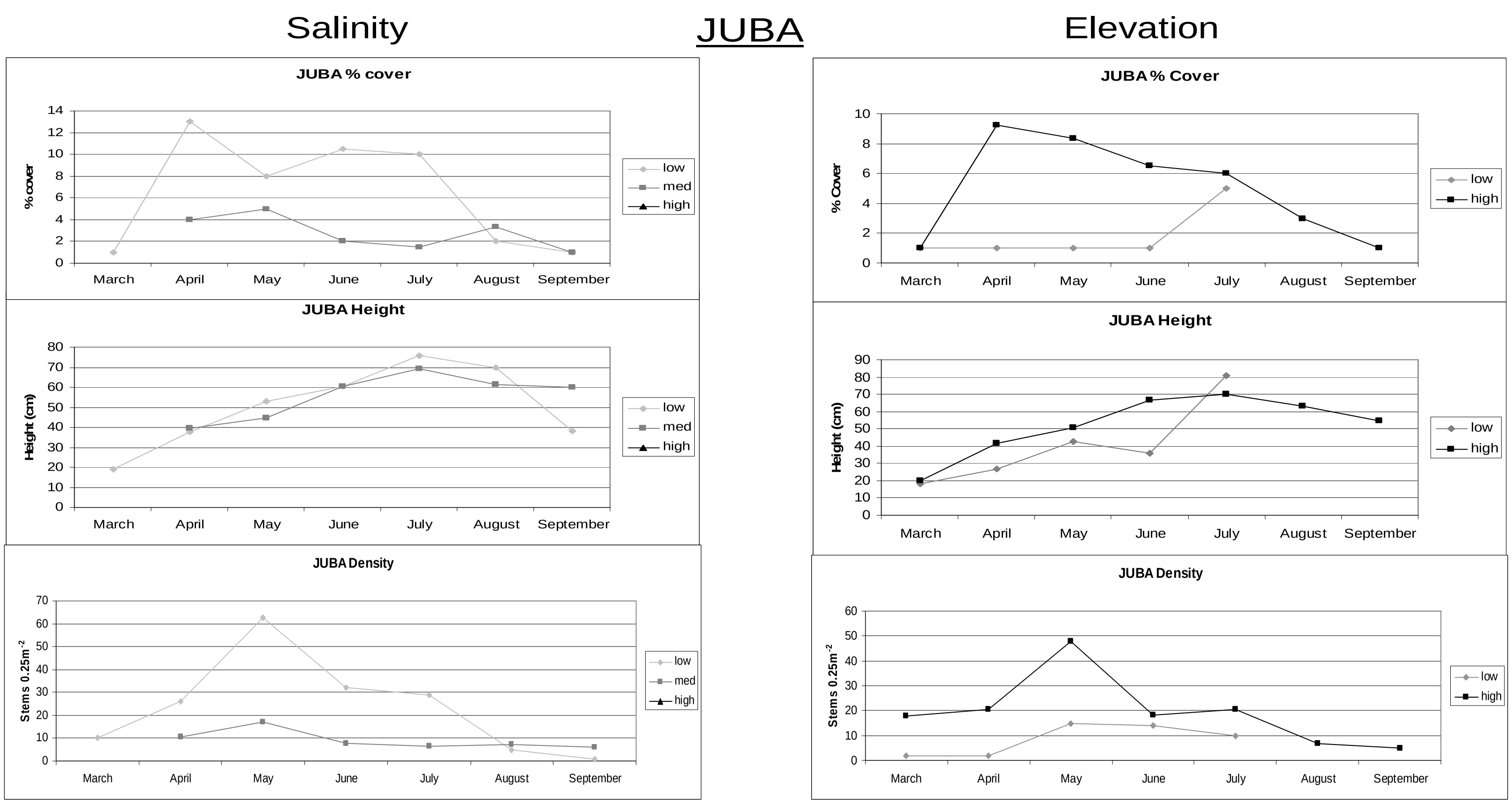


Figure 22: Seasonal growth patterns of *Juncus balticus* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

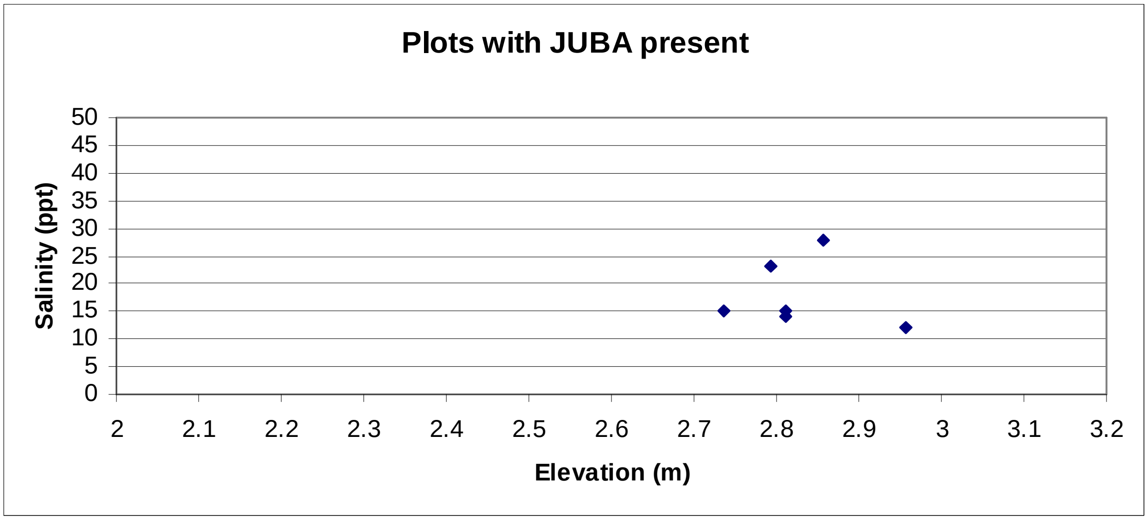


Figure 23: Soil pore-water salinity and elevation of the plots where *Juncus balticus* was present.

3.4.6 *Potentilla anserina*

For *Potentilla anserina* pore-water salinity showed very weak negative relationships with percent cover, height, and density (p-value > 0.1); while elevation showed significant positive relationships with percent cover, height, and density (p-value < 0.01; Table 2; Figure 24). The seasonal analysis of *Potentilla anserina* reveals similar relationships; with presence only detected in the mid salinity and high elevation areas (Figure 25). Although *Potentilla anserina* was present in only 9 of the 51 annual plots and 3 of the 21 seasonal plots the results still indicate that it may not be adapted to withstand high salinity environments, and is not capable of withstanding long term inundation either (Figure 26). These data suggest that *Potentilla anserina* is likely to be present only at locations within the Nisqually estuary that are at higher elevation with a significant freshwater influence. However, *Potentilla anserina* appeared in so few plots that the trends I detected may not be representative of the entire population. More data on this species is needed to confirm the observed trends.

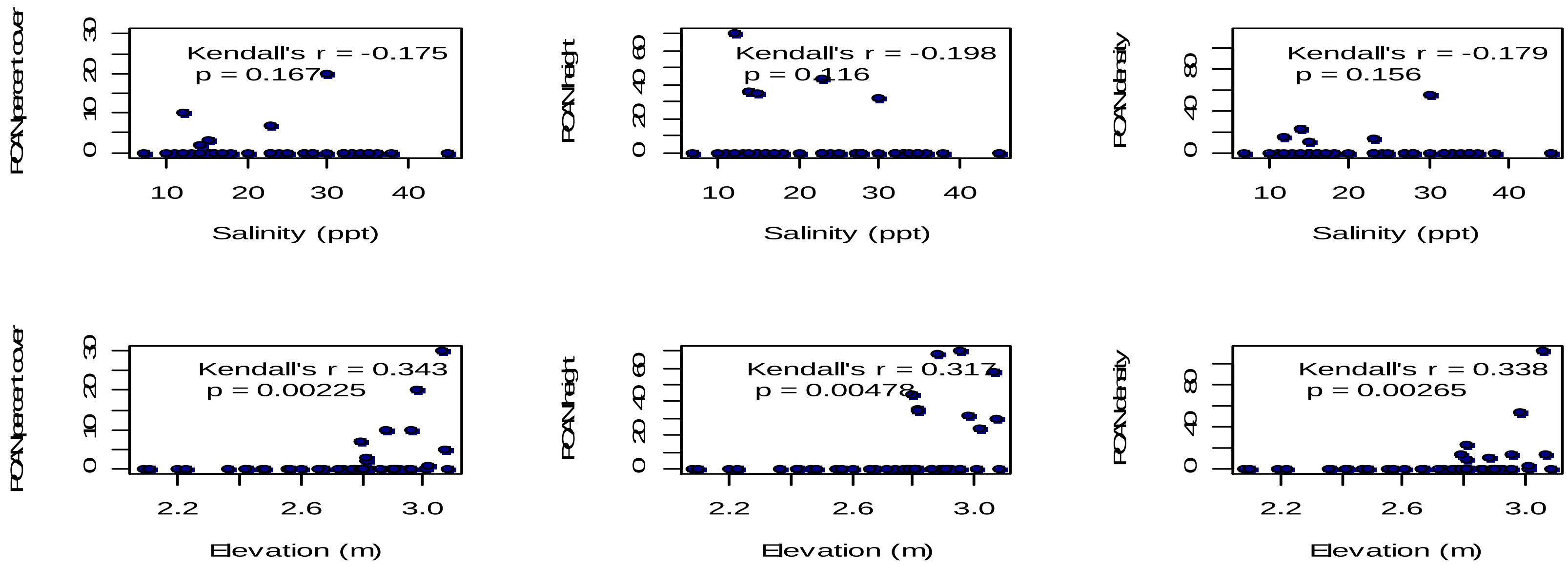


Figure 24: Kendall's correlation analysis of *Potentilla anserina* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

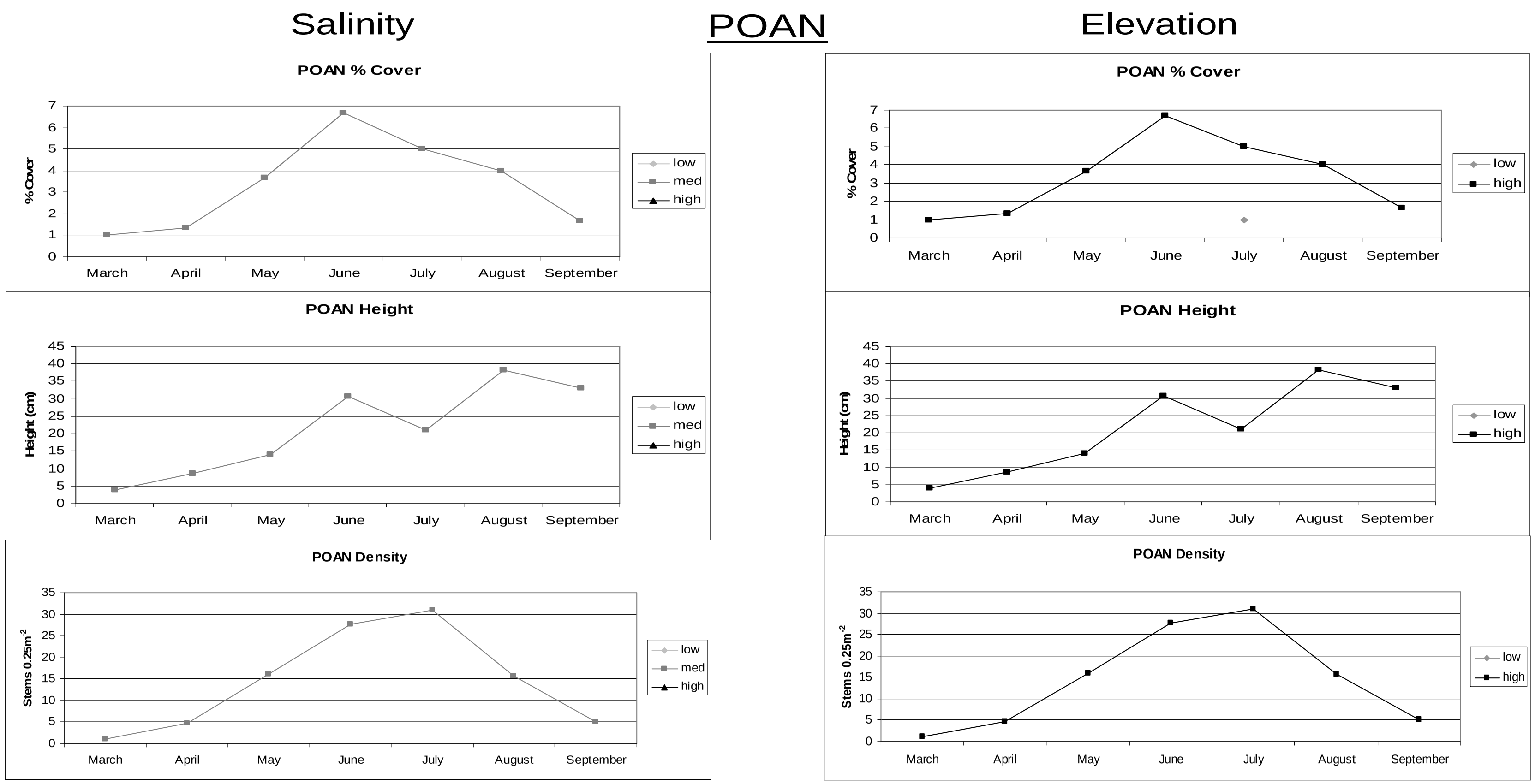


Figure 25: Seasonal growth patterns of *Potentila anserina* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

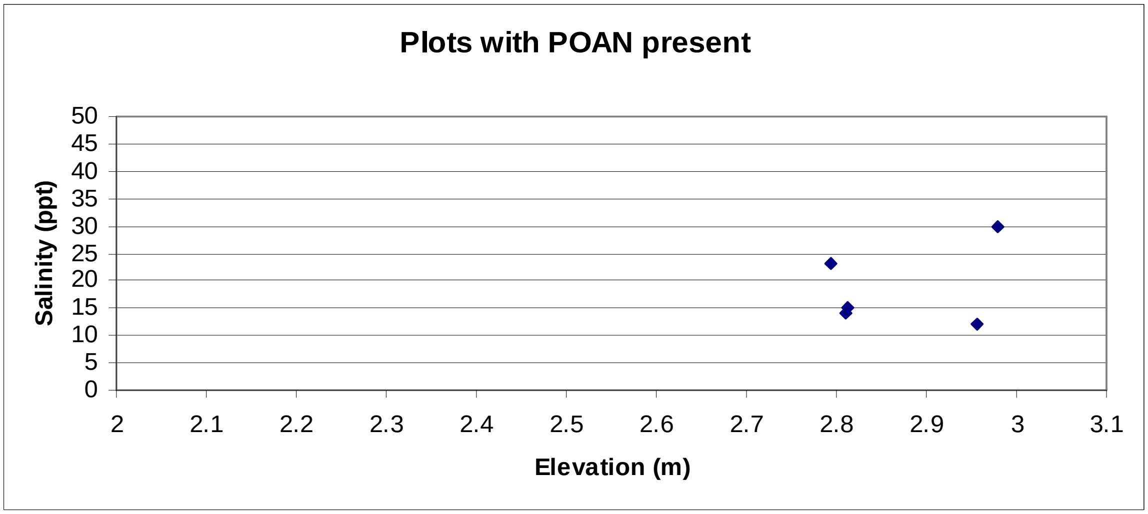


Figure 26: Soil pore-water salinity and elevation of the plots where *Potentila anserina* was present.

3.4.7 *Salicornia virginica*

For *Salicornia virginica* pore-water salinity showed significant positive relationships with percent cover, height, and density (p-value < 0.01; Table 2; Figure 27). Elevation did not show significant relationships with percent cover, height, or density (p-value > 0.1). The seasonal analysis of *Salicornia virginica* reveals different relationships; with maximum percent cover and height observed in the low salinity areas, maximum density observed in the medium salinity areas, and low elevations reaching maximum percent cover and density (Figure 28). *Salicornia virginica* was one of the most dominant species observed in the Nisqually Delta, with a presence in 24 of the 51 annual plots and 10 of the 21 seasonal plots (Figure 29). *Salicornia virginica* has rather large salinity and elevation tolerance ranges (Figures 7 & 8). These data suggest that *Salicornia virginica* is likely to be present throughout the entire Nisqually estuary, with an increased presence in the lower elevations with high pore-water salinity. However, these data are somewhat conflicting; the correlation analysis showed a positive relationship with pore-water salinity, while the seasonal analysis showed increased growth in areas with lower pore-water salinity. Also, the seasonal analysis showed increased growth in the lower elevations while the presence graph showed most occurrences to be in the higher elevations. This conflicting data indicates that another physical or biological parameter (such as; nutrient availability, soil type, pH, competition, herbivory, ect.) may be the determining factor in the distribution and growth of this species. More research on *Salicornia virginica* is needed to identify trends in growth and distribution.

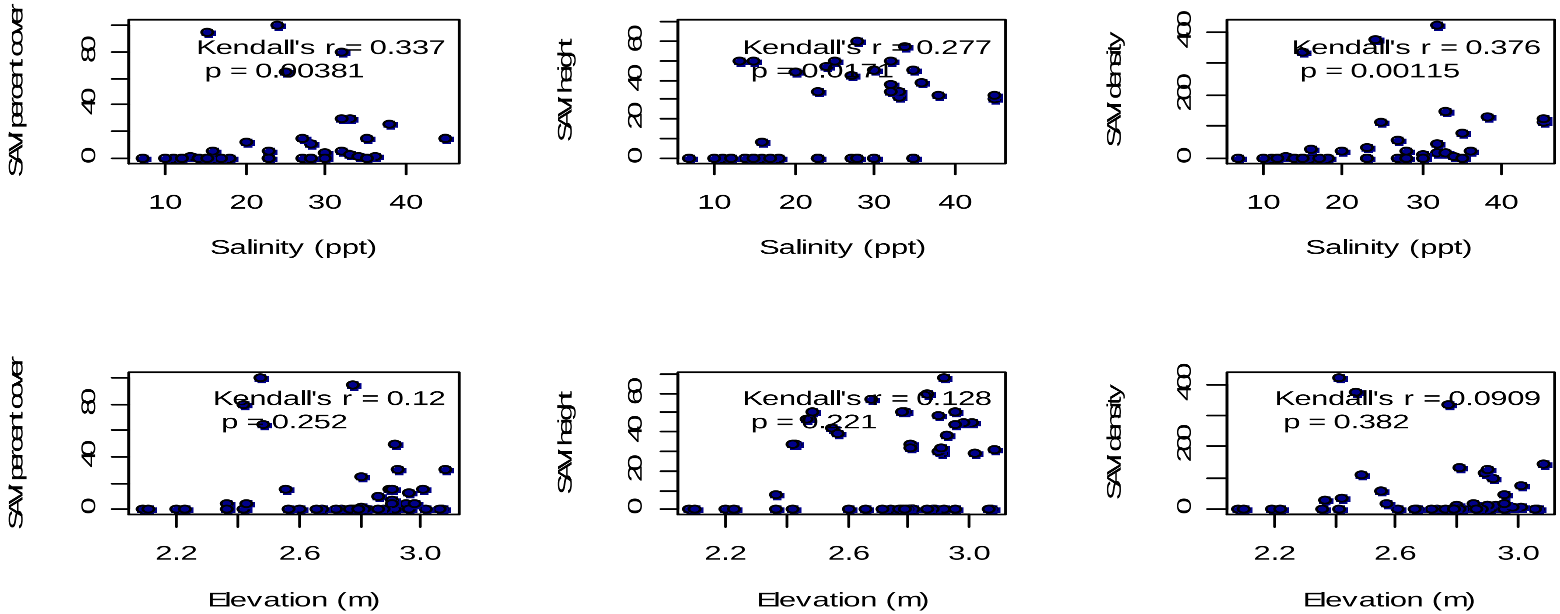


Figure 27: Kendall's correlation analysis of *Salicornia virginica* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

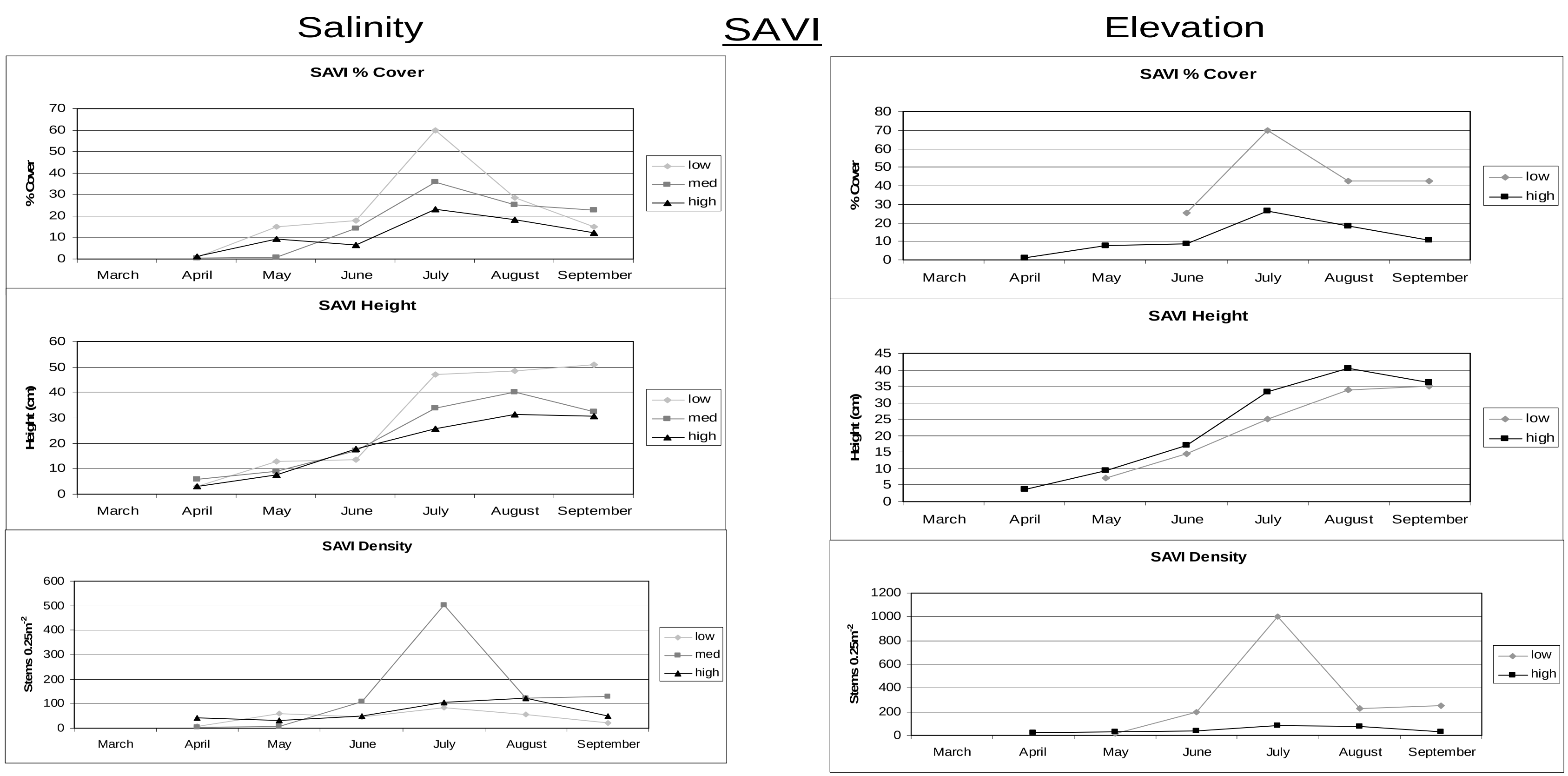


Figure 28: Seasonal growth patterns of *Salicornia virginica* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

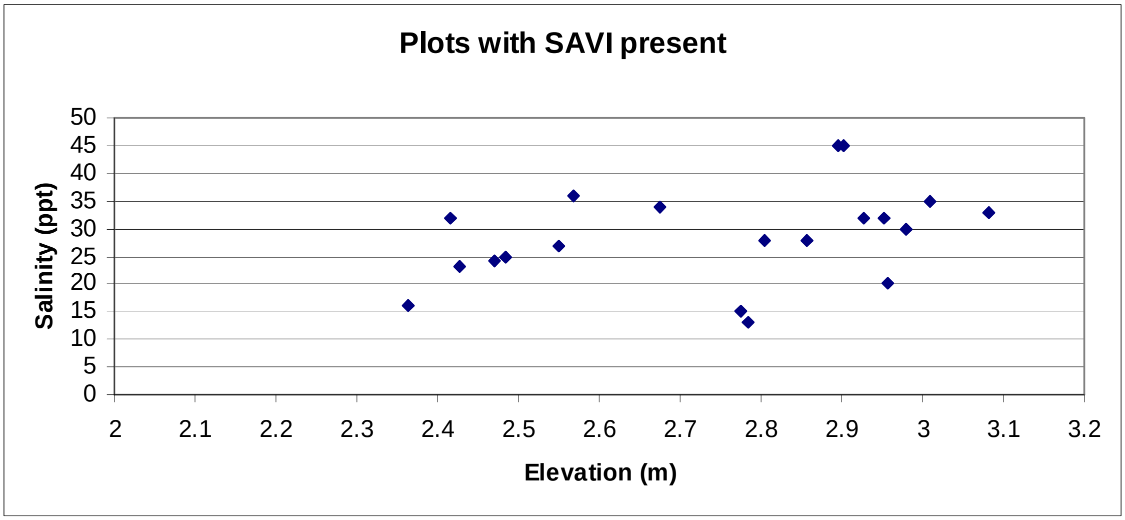


Figure 29: Soil pore-water salinity and elevation of the plots where *Salicornia virginica* was present.

3.4.8 *Spergularia sp.*

For *Spergularia sp.* pore-water salinity showed positive relationships with percent cover, height, and density (p-value < 0.1; p-value < 0.05; p-value < 0.1 respectively); while elevation showed no significant relationships with percent cover, height, or density of (p-value > 0.1; Table 2; Figure 30). The seasonal analysis of *Spergularia sp.* reveals slightly different relationships; with the maximum percent cover and density reached in the medium salinity and low elevation areas (Figure 31). *Spergularia sp.* was present in 13 of the 51 annual plots and 9 of the 21 seasonal plots, and the results of the presence graph indicate that *Spergularia sp.* may be adapted to withstand both high salinity and long term inundation environments (Figure 32). These data suggest that *Spergularia sp.* is likely to be present throughout the entire Nisqually estuary, with an increased presence in the lower elevations with high pore-water salinity.

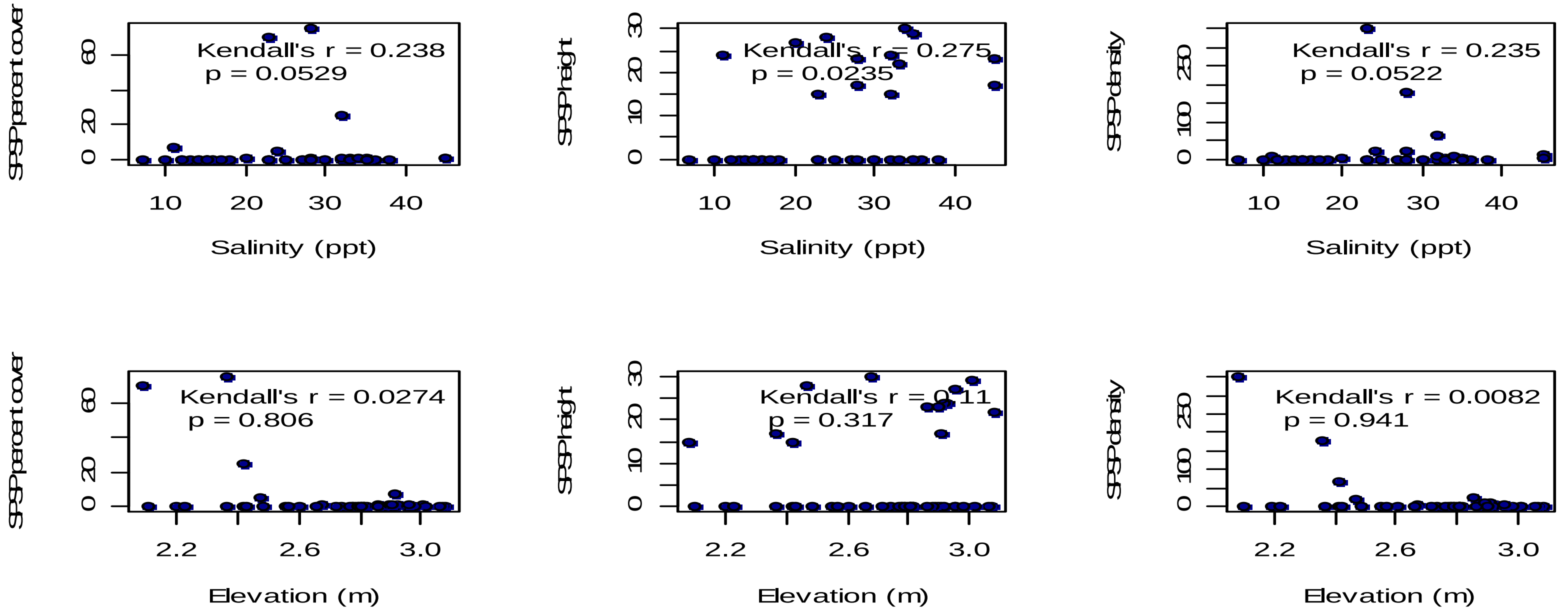


Figure 30: Kendall's correlation analysis of *Spergularia* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

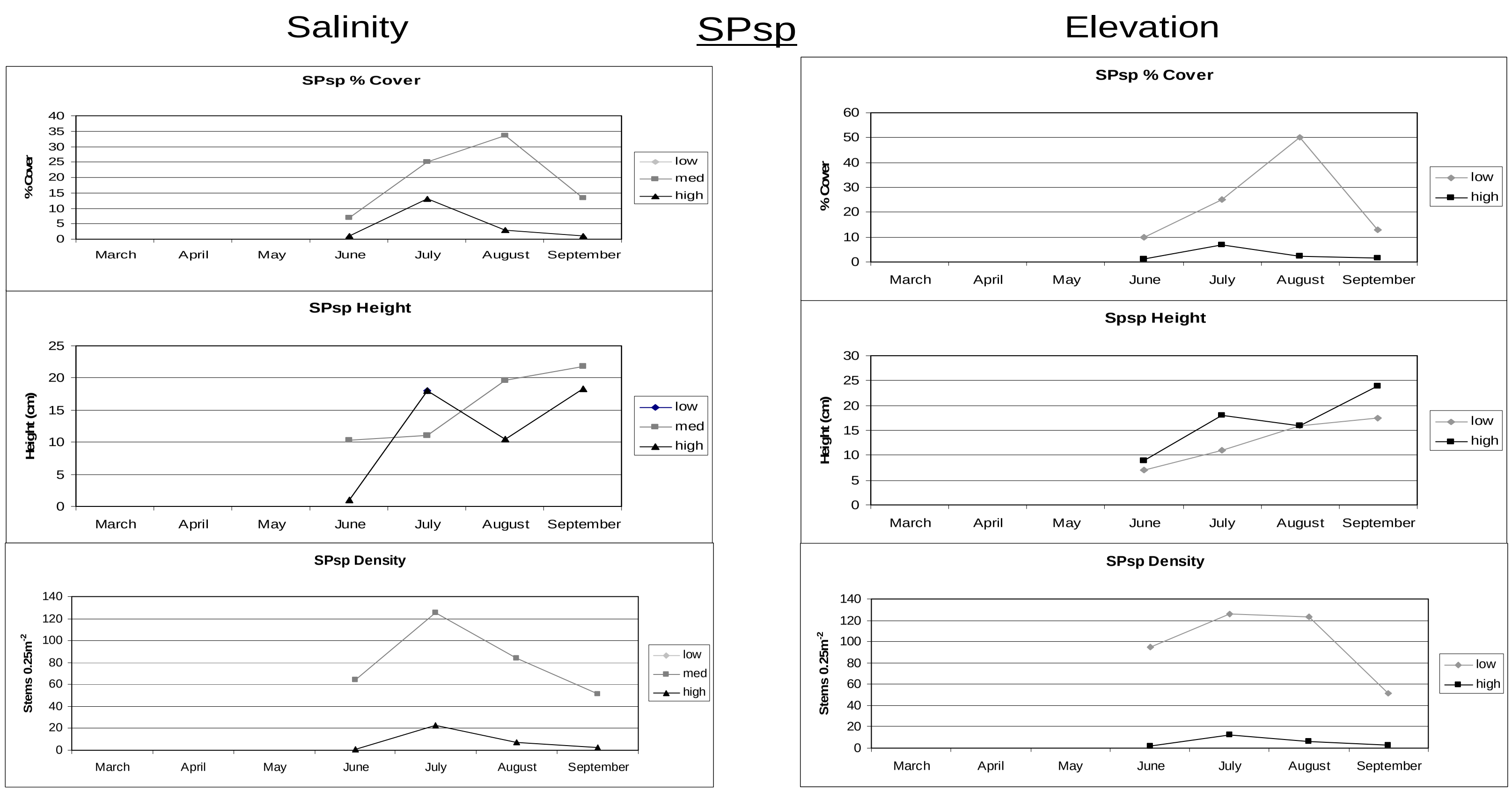


Figure 31: Seasonal growth patterns of *Spergularia sp.* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

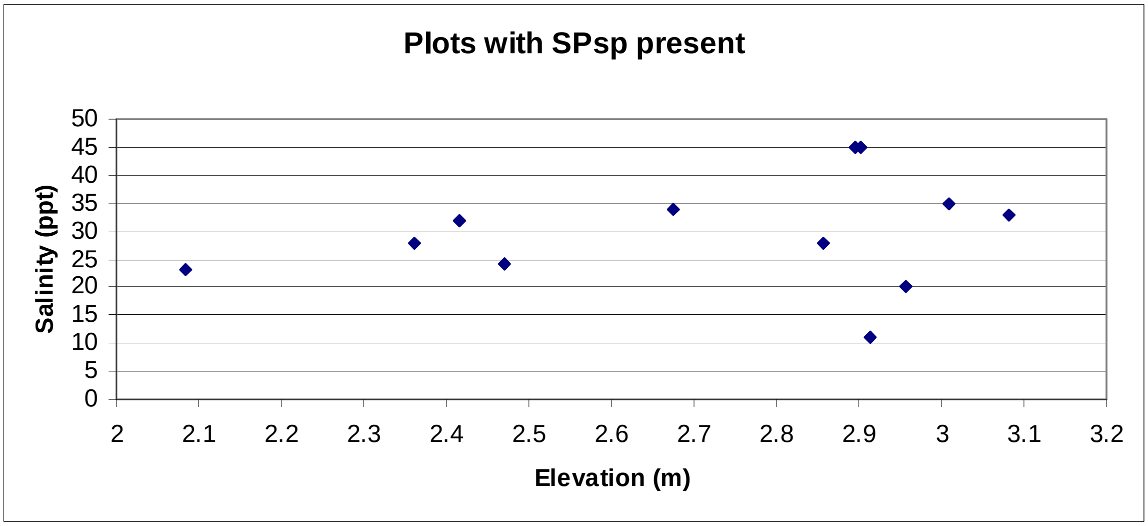


Figure 32: Soil pore-water salinity and elevation of the plots where *Spergularia sp.* was present.

3.4.9 *Triglochin maritimum*

For *Triglochin maritimum* pore-water salinity showed no significant relationship with percent cover, height, or density (p-value > 0.1); while elevation showed significant positive relationships with percent cover, height, and density of (p-value < 0.05, p-value < 0.05, p-value < 0.1, respectively; Table 2; Figure 33). The seasonal analysis of *Triglochin maritimum* reveals slightly different relationships, with maximum percent cover, height, and density reached in the medium soil pore-water salinity areas, while maximum percent cover and density occurred in the high elevation areas (Figure 34). *Triglochin maritimum* was present in 20 of the 51 annual plots and 11 of the 21 seasonal plots, and the results of the presence graph indicate that *Triglochin maritimum* may be adapted to withstand high salinity environments, but is not capable of withstanding long term inundation (Figure 35). These data suggest that *Triglochin maritimum* is likely to be present only at the locations within the Nisqually estuary that are at higher elevation, regardless of soil pore-water salinity.

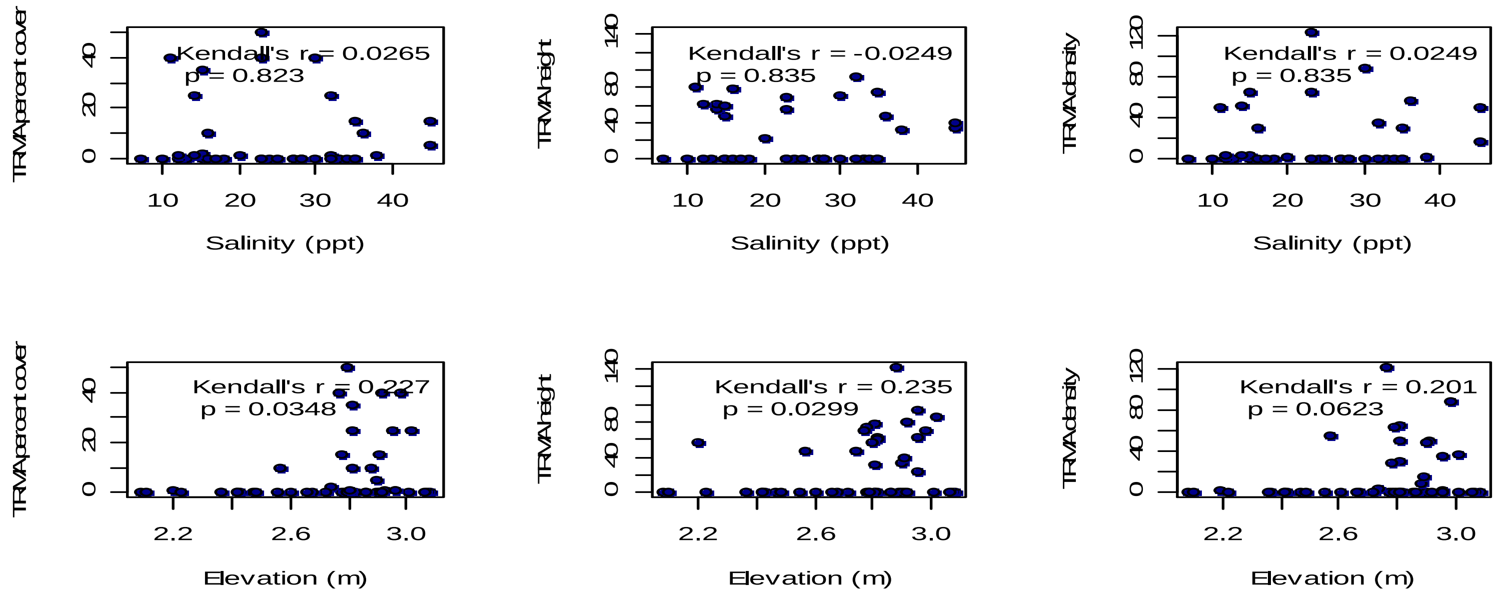


Figure 33: Kendall's correlation analysis of *Triglochin maritimum* percent cover, height, and density across salinity and elevation gradients within the Nisqually Delta.

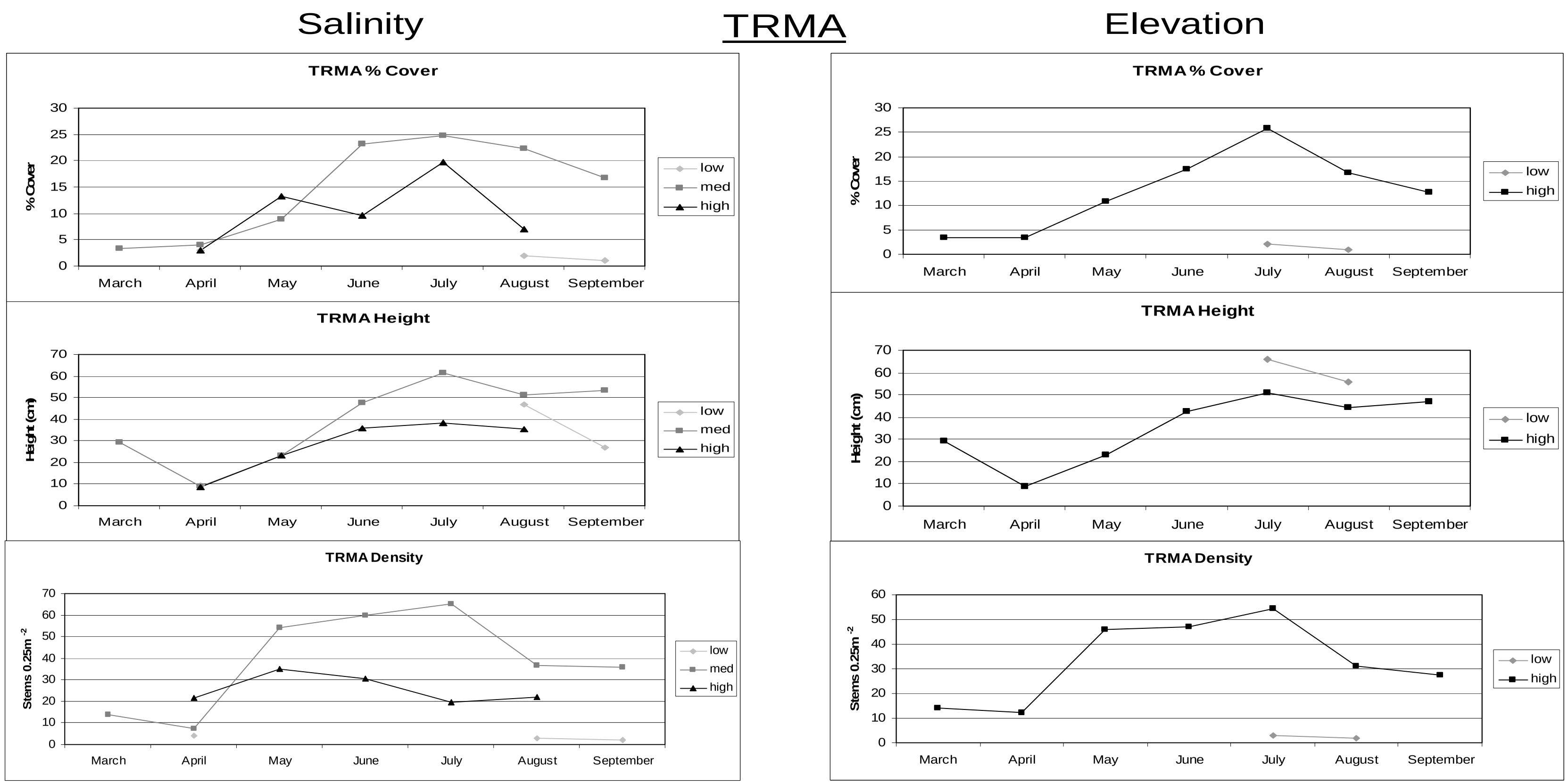


Figure 34: Seasonal growth patterns of *Triglochin maritimum* across salinity and elevation gradients within the Nisqually Delta. The salinity gradients are defined as low (<15ppt), med (15-25ppt) and high (>25ppt); and elevation gradients as low (< MHW) and high (>MHW).

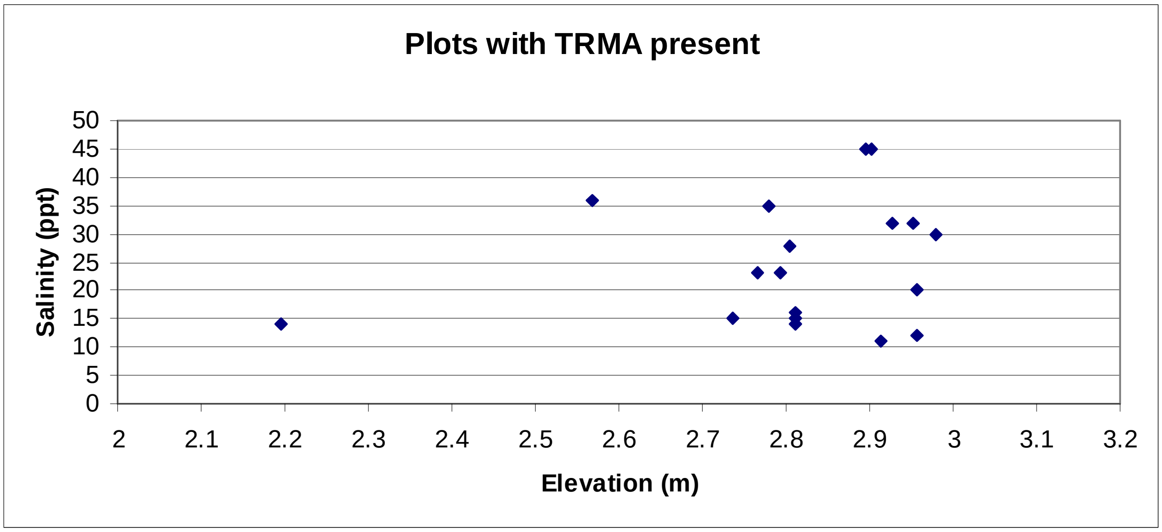


Figure 35: Soil pore-water salinity and elevation of the plots where *Triglochin maritimum* was present.

<u>3.5 *Comparison of expected and observed tolerance levels*</u>

When the results of this study are compared to what was hypothesized (Table 3) only two (*Carex lyngbyei* and *Distichlis spicata*) of the nine species analyzed responded as expected. Both *Grindelia integrifolia* and *Potentilla anserina* were present at higher salinities; *Jaumea carnosa*, *Juncus balticus*, and *Salicornia virginica* all showed presence in the high marsh elevations rather than keeping to the low marsh; and both *Spergularia sp.* and *Triglochin maritimum* showed results that diverge from the hypotheses for both salinity and elevation. *Spergularia sp.* (SPsp) was found throughout salinity and elevation gradients and is not limited to low marsh areas with medium to low salinity; and *Triglochin maritimum* was found in a range of salinities, most often present in the high marsh, not the low marsh.

Table 3: Salinity and elevation tolerance ranges expected versus results.

		Expected		**Nisqually (2010)**	
Spp. Code	**Scientific Name**	**Salinity (ppt)**	**Elevation**	**Salinity (ppt)**	**Elevation**
CALY	*Carex lyngbyei*	< 20	low and high	< 30	low and high
DISP	*Distichlis spicata*	50+	low and high	40+	low and high
GRIN	*Grindelia integrifolia*	< 15	high	> 20	high
JACA	*Jaumea carnosa*	10-40	low and high	4-45	low and high
JUBA	*Juncus balticus*	10-30	low to mid	5-28	low and high
POAN	*Potentilla anserina*	0-12	high	10-30	high
SAVI	*Salicornia virginica*	20-80	low	5-45	low and high
SPSP	*Spergularia sp.*	6-20	low	11-45	low and high
TRMA	*Triglochin maritimum*	0-21	low	10-45	low and high

The papers that Hutchinson (1988) reviewed were all studies based in the Pacific Northwest, however many of even these studies gathered salinity data from the closest water bodies rather using in situ data like this study did. Also Hutchinson (1988) converted all parameters and units described in the literature review into salinity in parts per thousand (ppt) in order to standardize the results. The resulting salinity values include information derived from soil, inundating water, and growing medium salinities. There can be significant differences in soil salinity versus the salinity of inundating waters. These factors could explain some of the differences between the results and hypothesized relationships.

Other factors that may explain the differences between the hypotheses and results are the many environmental factors influencing plant establishment, growth, and distribution, such as: soil chemistry (including organic matter, pollutants, and nutrients), type, and moisture; distance from channels, drainage/tidal retention time, water quality, and competition (Bornman et al. 2008, Gutrich et al. 2009, Howard 2010, Wolanski and Richmond 2008).

3.6 *Species Richness*

Species richness was expected to decrease as pore-water salinity increased because high salinity environments are stressful areas for plant survival. It was also expected that species richness would increase as elevation increased because many species seek refuge from inundation in the higher marsh. The results of this research showed no strong relationship between salinity and species richness (Figure 36); while the relationship between elevation and species richness was quite clear (Figure 37). The greatest number of species observed in the low marsh plots was six, and more often only two species are present in the low marsh plots. However, in the high marsh there were often six or more species present in one plot.

The number of species present varies throughout all salinity values, most likely due to the fact that many salt marsh species have adapted to the higher salinities and have large tolerance ranges. More species are present at higher marsh plain elevations, most likely due to the fact that many species are not adapted to inundation (i.e. lower elevations); therefore occur at higher elevations to avoid the long inundation times.

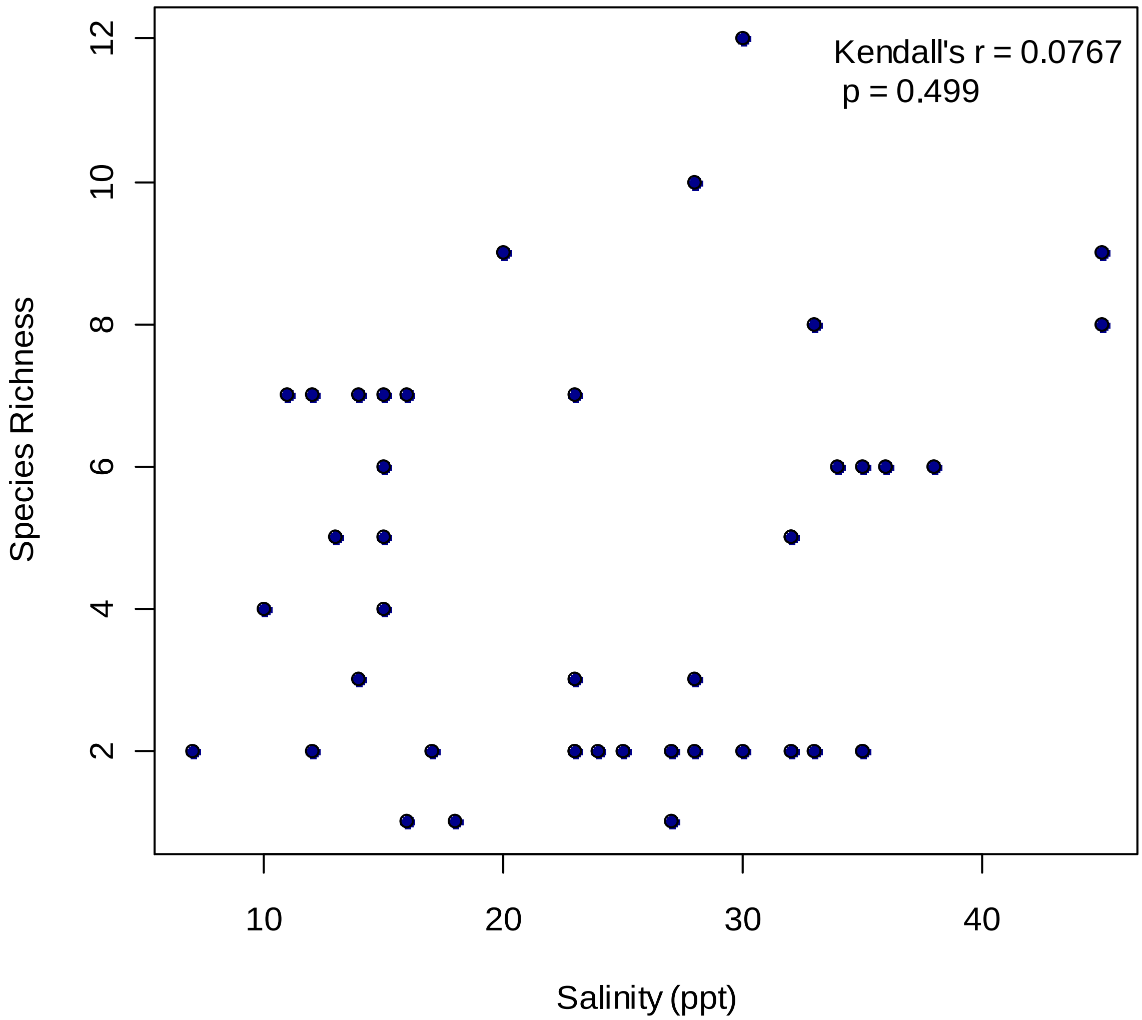


Figure 36: Species richness versus soil pore-water salinity. For this research salinity ranges were established as low (<15ppt), medium (15-25ppt), and high (>25ppt).

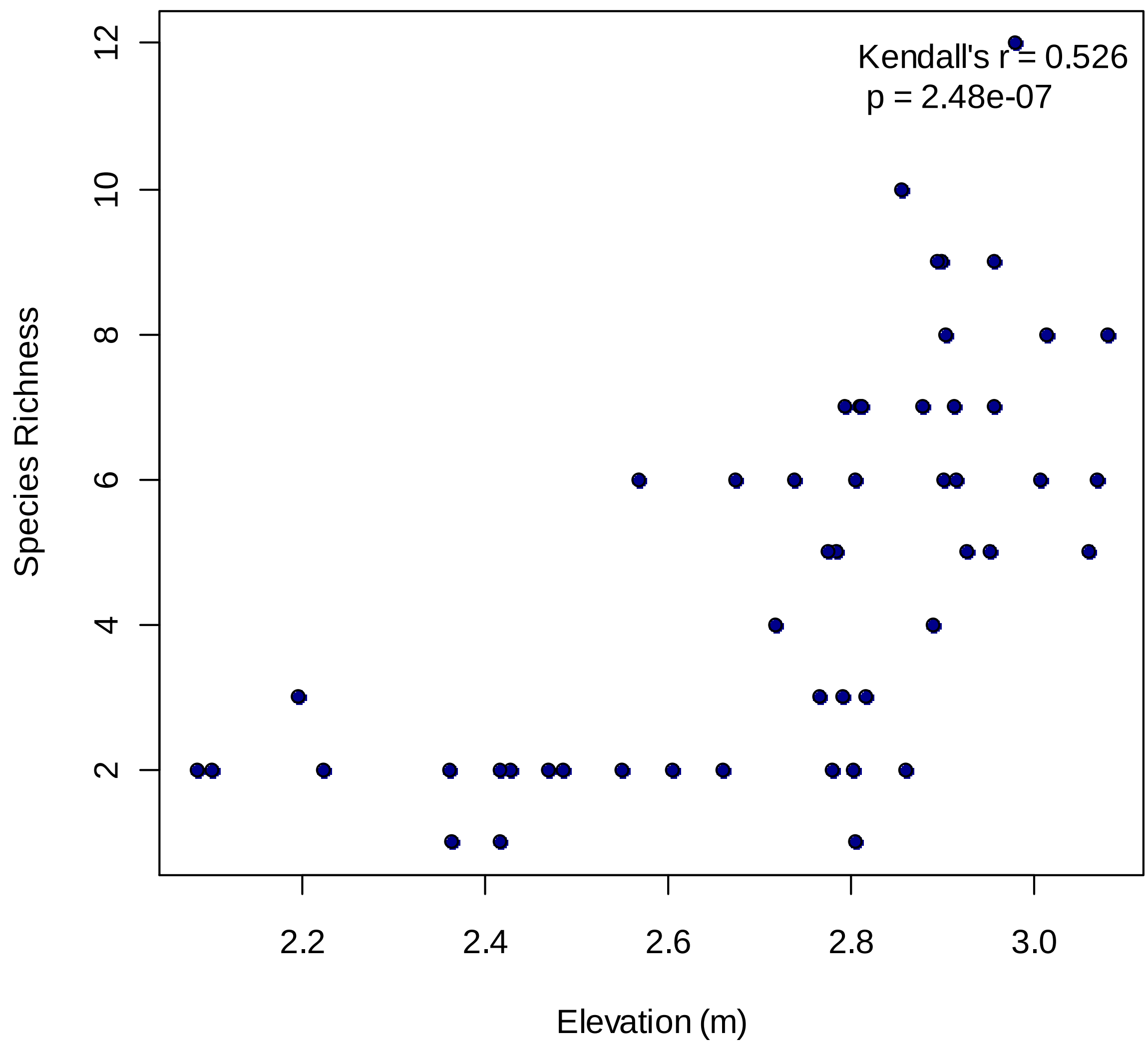


Figure 37: Species richness versus elevation. For this research the separation between high and low marsh was established at 2.7m.

<u>3.7 *Site Conditions of the Restoration Area on the Nisqually National Wildlife Refuge*</u>

Within the Nisqually National Wildlife Refuge (NNWR) estuary restoration area there are five tidal slough channels which are the location of fifteen survey locations (Unit 1, 2, 3, 4, and Madrone; Figure 2). Survey locations along each slough were established at the north (mouth), middle, and the southern (most inland) portion of the channel (Figure 3). The pore-water salinity of the survey locations within the restored area of the NNWR varied from as low as 3 ppt to 32 ppt over the 2010 survey season (Figure 38). Most salinity values of these sites fell within the brackish (15-25 ppt) to marine (>25 ppt) salinity range. Two sites (Unit 3 middle and south) averaged a salinity value of <15 ppt (fresh); five sites (Unit 3 north, Unit 2 north and mid, Unit 4 mid, and Madrone mid) averaged 15-25 ppt (brackish); and eight sites (all of Unit 1, Madrone north and south, Unit 4 north and south, and Unit 2 south) averaged >25 ppt (marine). Unit 3 averaged the three lowest pore-water salinity values; most likely due to the proximity of Unit 3 to the Nisqually River, whereas the rest of sites within the restored area on the NNWR are more influenced by the waters of Puget Sound resulting in higher salinity values (Figure 2).

The elevations of the fifteen survey sites along the five main slough channels in the NNWR restoration area range from 1.12-2.97 m, with the maximum elevation at Unit 2 south and the minimum at Unit 2 north (Figure 38). None of the sites averaged an elevation above the MHW (2.71 m) level, and only three transects (Unit 2 mid and south, and Madrone north) had a maximum elevation at some point that occurred within the high elevation range (>2.71 m). The low elevations on the Refuge are likely due to the lack of sediment influx and subsidence over the last century in response to the land alterations for farming.

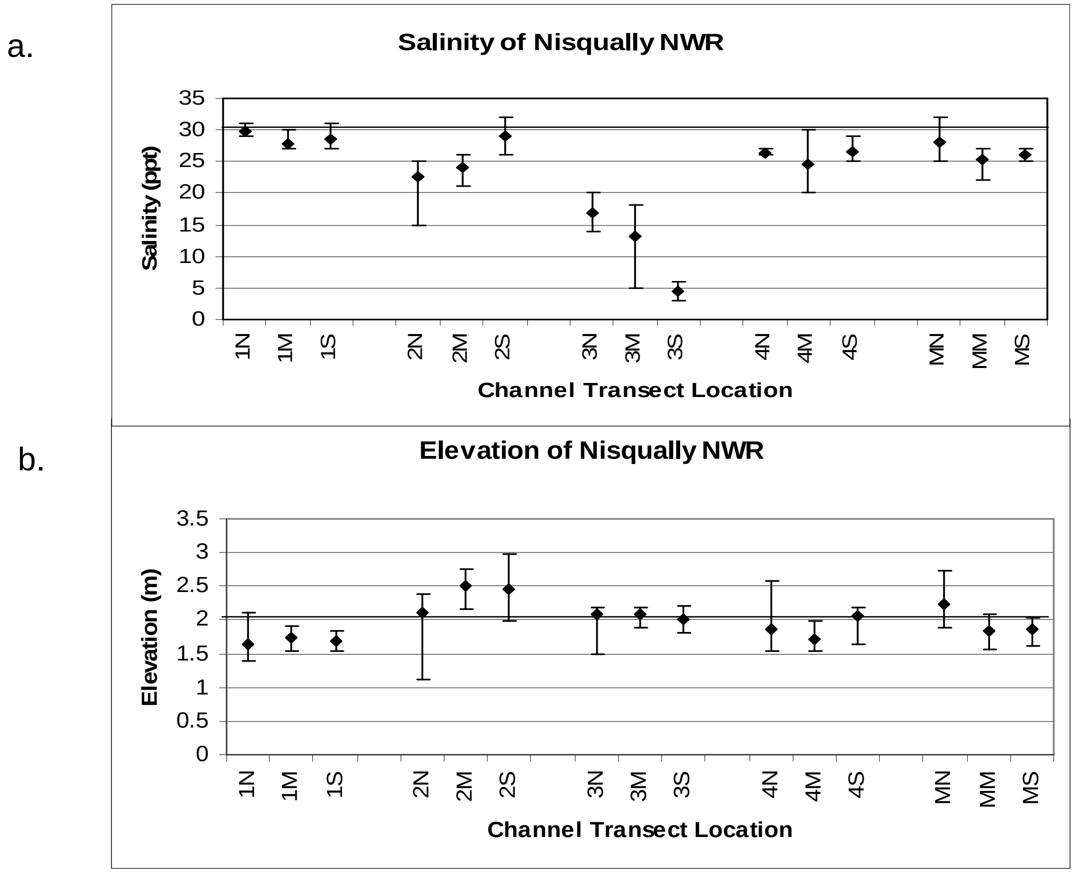


Figure 38: Pore-water salinity and elevation ranges of the study sites on the Nisqually National Wildlife Refuge in 2010. The dot represents the mean and the error bars represent the maximum and minimum elevation values. The number indicates the study unit and the letter indicates the station (North, Middle or South). Both the salinity (30 ppt) and elevation (2 m) thresholds established by this research are highlighted here.

Vegetation data from the NNWR survey locations were not used in this research because the recent restoration activities would be the dominant factor affecting vegetation growth and distribution. However, the salinity and elevation data can be used along with the vegetative results of this research to predict habitat types likely to colonize the recently restored site. The results of this research indicate a salinity threshold of 30 ppt for some salt marsh species (Figure 7). Most of the survey locations on the NNWR are at or below this threshold, which means that salinity will most likely not be the limiting factor for salt marsh vegetation establishment in the newly restored estuary. The results above also indicate an elevation threshold of 2 m below which no vegetation was observed. Most of the survey locations on the NNWR are below this elevation threshold indicating a need for sediment influx. However, according to the 2011 LIDAR data (Figure 39) over half of the NNWR estuary restoration area is currently at elevations that are capable of supporting salt marsh vegetation (>2 m), and since the dike removal in 2009 sediment accretion has been measured across the restoration site (Turner et al. 2011).

Since submergence time (i.e. elevation) appears to be the dominant factor for estuarine vegetation growth estimations are not based solely on the fifteen survey location's elevation data but are combined with LIDAR data to capture more elevation coverage of the restored estuary. The habitats likely to be found within the restored estuary on the NNWR are mudflat (<2 m), low marsh (2 - 2.7 m (MHW)) and high marsh (>2.7 m (MHW); Figure 39). According to the LIDAR over half of the NNWR estuary restoration area is currently at elevations that are capable of supporting salt marsh vegetation (>2 m). Most salt marsh species in this study were detected at a minimum elevation of 2.5 m (NAVD88) which represents approximately 16% of the NNWR restoration site. Of that, approximately 9% is considered high marsh (>2.7); which is where, according to this research, the greatest diversity of species is present. However, *Carex lyngbyei* was found to be negatively influenced by both pore-water salinity and elevation (Table 2) suggesting that areas within the restored estuary that have lower elevations with a significant freshwater influence may not become unvegetated mudflat, but rather dominated by *Carex lyngbyei*. Both *Distichlis spicata* and *Spergularia* sp. are able to withstand low elevations and high pore-water salinity suggesting that a large portion of the NNWR will be dominated by these two species. The higher elevations within the restored estuary are likely to contain a diversity of salt marsh species, and the higher areas with a freshwater influence is where it will be likely to find *Juncus balticus* and *Potentilla anserina*.

Nisqually Refuge Elevation Ranges & Vegetation Transects

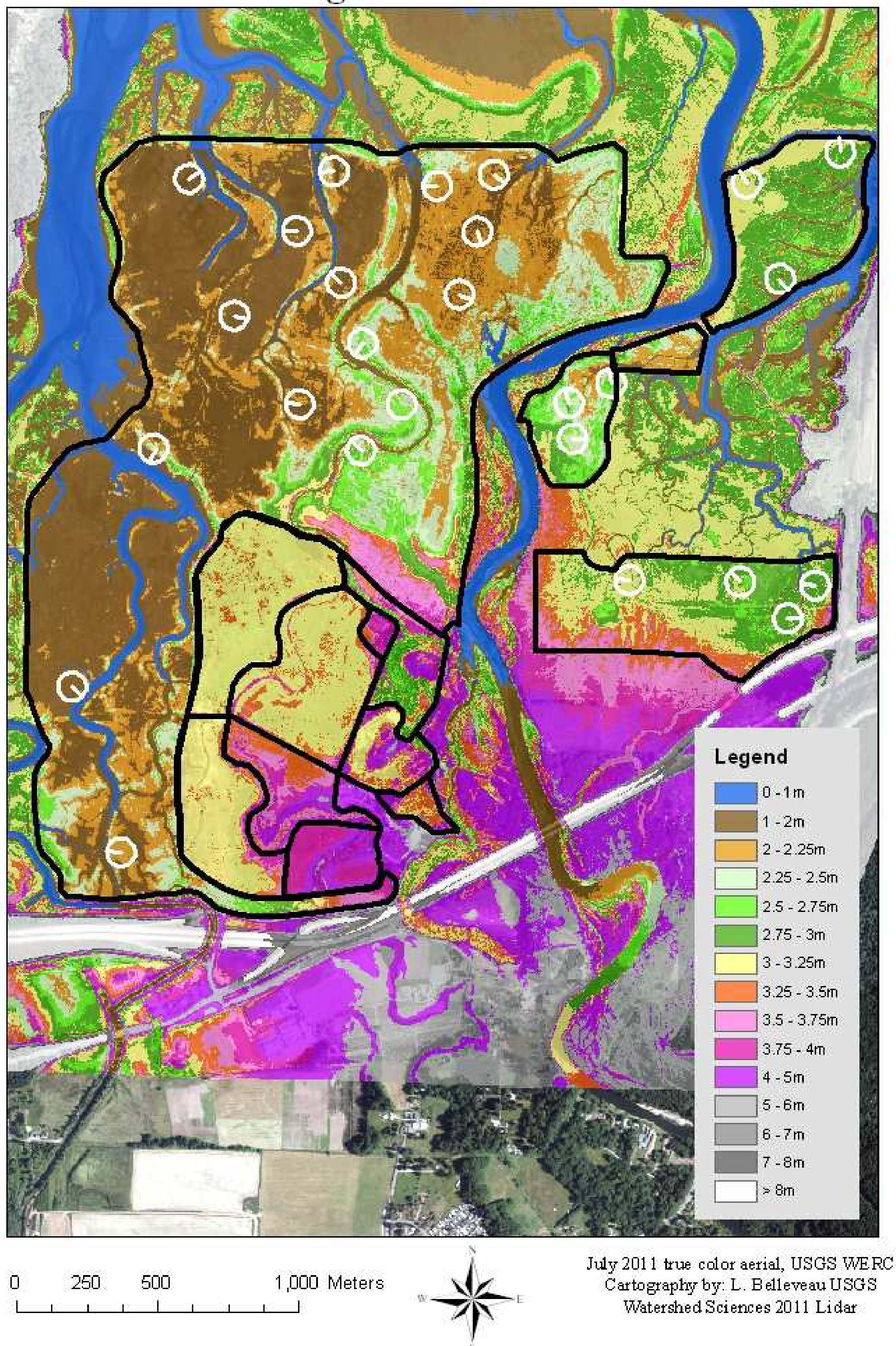


Figure 39: Elevation of the Nisqually Delta based on a 2011 LIDAR flown by Watershed Sciences.

4. CONCLUSION and RECOMMENDATIONS

The Nisqually River Delta is an estuary that has been modified by restricting tidal flow to reclaim lands for agriculture. Recently, the Nisqually National Wildlife Refuge, working in collaboration with the Nisqually Indian Tribe and Ducks Unlimited, restored a large amount of the tidal flows as part of the largest estuary tidal marsh restoration project in the Pacific Northwest.

Over time, salt marsh vegetation has adapted to withstand the high salinity and periodic inundation associated with intertidal landscapes. This thesis explored this relationship in the salt marshes of the Nisqually Delta in order to quantify the tolerance ranges as well as the optimal growing conditions for several common salt marsh species. This research provides knowledge that can be used to identify suitable locations for salt marsh habitat restoration, and to ensure successful colonization of native species.

Vegetation survey results above indicate an upper salinity threshold of 30 ppt for some salt marsh species. Most of the survey locations on the NNWR are at or below this threshold, which means that salinity will most likely not be the limiting factor for salt marsh vegetation establishment in this newly restored estuary. The results above also indicate an elevation threshold of 2 m below which no vegetation was observed. Over half of the NNWR estuary restoration area is currently at elevations that are capable of supporting salt marsh vegetation (>2 m). This research shows that both pore-water salinity and elevation have a positive influence on the salt marsh vegetation species studied. Indicating that these species can tolerate high salinities, but submergence time (i.e. elevation) may be the dominant factor explaining differences in their growth and distribution.

This thesis examined salinity and elevation influences on vegetation, however, there are several environmental factors influencing plant establishment, growth, and distribution, such as: soil chemistry (including organic matter, pollutants, and nutrients), type, and moisture; distance from channels, drainage/tidal retention time, water quality, and competition. Bornman et al. (2008) found that soil moisture was most influential on species with large salinity tolerance ranges, while species with narrow salinity ranges were limited by salinity and thus forced into drier habitats or areas with freshwater influence. Howard et al. showed that soil type and salinity were significantly related, and that soil type was a determining factor in plant growth in Louisiana marshes. Future research suggestions include continued monitoring of the Nisqually Delta vegetation along with the sedimentation and subsidence processes that affect their distribution and colonization success, as well as studying more environmental factors that may be contributing to salt marsh vegetation growth and distribution.

Currently, there is concern in the Pacific Northwest about the condition of Puget Sound and the many estuarine habitats along the shoreline. Most of these estuaries have been degraded due to anthropogenic activities and are in need of restoration. Restoration of any landscape takes many years, but since the dike removal in 2009, sediment accretion has already been measured on the NNWR restoration site. In estuaries, salt marsh vegetation helps trap and stabilize sediment leading to additional sediment accretion and thus increased elevations over time (Adam 1990). Restoration of the Nisqually Delta has the potential to expand critical habitat for threatened salmon species, migratory birds, as well as contribute to the recovery of the Puget Sound ecosystem. The full removal of the dike at NNWR, as opposed to breaches, allows for more connectivity and sediment deposition avenues throughout the landscape; thus increasing the ability of the restoration site to build elevation levels, a key factor in salt marsh vegetation growth and distribution.

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