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Sediment and vegetation monitoring during a levee removal project on the Stillaguamish River Delta at Port Susan Bay, WA

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**SEDIMENT AND VEGETATION MONITORING
DURING A LEVEE REMOVAL PROJECT
ON THE STILLAGUAMISH RIVER DELTA
AT PORT SUSAN BAY, WA**

By

Alec Barber

Accepted in Partial Completion
of the Requirements for the Degree
Master of Science

Kathleen L. Kitto, Dean of the Graduate School

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Chair, Dr. John Rybczyk

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MASTER'S THESIS

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Alec Barber
October 20, 2014

**SEDIMENT AND VEGETATION MONITORING DURING A
LEVEE REMOVAL RESTORATION PROJECT
AT PORT SUSAN BAY, WA**

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By
Alec Barber
October 2014

ABSTRACT

Sea levels around the world are on the rise in due to the effects of climate change. Coastal wetlands and estuaries are at risk of being submerged as water levels continue to increase, unless they can move inland or gain surface elevation. These wetland systems provide vital ecosystem services that would be difficult or impossible to provide by other means. In the Puget Sound, Washington, 80% of the original estuarine and coastal wetland habitat has been replaced by human infrastructure, making the monitoring, preservation, and restoration of the remaining stock important both ecologically and economically. The objective of this project was to monitor the restoration of an estuarine system on the Stillaguamish River delta. The project involves the removal of levees and reintroduction of tidal flow into a subsided farmland that was formerly part of the estuary, and to determine the sustainability of the Stillaguamish River delta and similar Puget Sound estuaries with rising sea-levels. The scope of this monitoring project includes the installation and yearly sampling of surface elevation tables (SETs), vegetation surveys and quantification of the net primary productivity (NPP) within the leveed area, immediately outside the levees, in an adjacent area outside the farmland, and within an un-leveed reference site across the main river channel. SET sampling, before the levee removal, revealed a positive trend in elevation gain at 8 of the 11 SETs of over 1 cm/year, well above current rate of RSLR at 0.19cm/year. Sediment markers revealed that most of that gain can be attributed to sediment accretion, indicating adequate sources of sediment and therefore sustainability of the estuary under current rates of sea level rise. Primary productivity sampling in the late summer of 2012 yielded an average of 420 DW(g)/m²/year in the high marsh and 327

DW(g)/m²/year in the low marsh sites. Vegetation consisted predominantly of *Schoenoplectus americanus*, *Schoenoplectus acutus*, and *Schoenoplectus maritimus*, with elevation delineating the greatest shifts in community structure and abundance. The exception to this was within the portion of leveed farmland, where surface elevations were below the surrounding estuary and vegetation consisted primarily of a *Schoenoplectus americanus* monoculture.

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1 INTRODUCTION

The effects that climate change has on coastal communities are an inarguable reality, with many recent examples in the media of the destructive potential of increased storm frequency and rising sea levels on human infrastructure. Estuarine habitats have historically been the buffer between the sea and inland landscapes, attenuating the energy of storm surges and creating a transitional area between fresh and salt water environments. Specially adapted plant species inhabit this brackish zone between the salt and fresh water; these species have been historically capable of maintaining surface elevations in response to changes in sea level, maintaining an equilibrium, but their persistence under current conditions is not certain. In this paper I observed current sediment dynamics under sea level rise within a Puget Sound Estuary and attempted to determine how vegetation species and their productivity influence surface elevation processes.

1.1 Estuarine systems

1.1.1 Economic and ecological value of estuaries

Estuaries form at the transition zone from the river into the sea, resulting in the mixing of freshwater and saltwater, and the deposition of both ocean and river derived nutrients and sediments. The result of these oceanic and terrestrial inputs is a landscape with a uniquely high potential for productivity, with coastal wetlands being placed as one of the most valuable systems on the planet (Day et al. 1989). These systems provide essential ecosystem goods and services which cannot be easily replaced, such as carbon storage, improved water quality through biological and physical processes, nutrient cycling and the entrapment of organic material and pollutants in sediments and vegetation. Estuarine

vegetation also provides habitat and food for numerous species, including juvenile salmon, migratory birds, and many invertebrates.

In a global assessment of the economic value of ecosystems, it was estimated that the ecosystem goods and services provided by estuaries are worth about \$23,000 ha⁻¹yr⁻¹ (Costanza et al. 1997). Batker et al. (2008) conducted a more recent monetary valuation of the Puget Sound region in Washington, indicating that estuaries and salt marsh systems have the highest value per unit of all the ecosystem types examined, with estimates closer to \$200,000 ha⁻¹yr⁻¹ combined. Though differing in values, both of those studies apply values to the ecosystem services provided by wetlands at a point many times higher than the landscapes often replacing them by development, such as farmlands. A significant contributor to the high valuation is that coastal wetlands are a key component in storm damage mitigation, through the attenuation of flood waters and storm surges in vegetation buffers, lessening the damage to human infrastructure caused by storm events by as much as \$40,000 ha⁻¹yr⁻¹ (1997) to \$96,000 ha⁻¹yr⁻¹ (2008) (Batker et al. 2008, Leschine and Petersen 2007).

1.1.2 Human impact on estuarine systems

The greatest threats to estuaries have been due to anthropogenically induced habitat destruction, with current losses largely due to the stabilization of shorelines for infrastructure protection and further urban development around coastal areas (Mitch and Gosselink 2007). In the Puget Sound region, those historical losses were largely from the development of the fertile floodplains for agricultural use, termed reclamation. The reclamation of wetland areas was accomplished through draining, dredging, filling,

construction of impoundments in the form of levees and dams, and installation of riprap armoring along banks and shorelines, leading to the significant loss of wetland habitats around the world (Mitch and Gosselink 2007). The effect of this since modern European settlement is that an estimated 65% of wetlands within the United States have been developed or drained (Ramsar 2004).

1.1.3 Restoration of estuarine systems and sustainability

The high value and current scarcity of healthy estuarine ecosystems has led to the current conservation and restoration of many estuaries, attempting to undo the damage caused by generations of human exploitation. The definition of restoration in many cases is defined as the return of a system to a pre-disturbed state (NRC 1994). In reality, human development will continue to occur, with population projections for coastal regions predicting further increase, making maintaining even the current conditions difficult and reaching pre-disturbance conditions an unachievable goal (Baird 2005). A better path for restoration is setting goals that aim for restored ecosystem function and sustainability with objectives based on the local constraints of each project (Simenstad et al. 2006).

1.2 Estuarine surface elevation dynamics

1.2.1 Sea level rise

The human impact on estuary loss goes beyond the direct destruction, as many estuarine systems are in danger of further losses due to climate change and the effects this has on developed coastal regions, potentially destroying what is left of the remaining systems through the permanent inundation of seawater (Nicholls 2004). The rates of sea level rise predicted by the 2007 Intergovernmental Panel on Climate Change (IPCC) through

several climate change scenario models show an increase in sea levels from 18cm to 59cm over the next century (Meehl et al. 2007). Those predictions may not be accurate, as it has been indicated that estimates by the IPCC are considered too conservative, with a corrected global mean sea level rise (GMSLR) over the last century placed at around 1.6mm per year, a pace that is already on a higher trend than the maximum projections of the IPCC report (Woppelman et al. 2009). More recently, Jevrejeva et al. (2012) created a model that better fits with the currently observed rates of rise, almost doubling the range of rise predicted by the IPCC, increasing global sea level rise to 57-110cm over the next century. The current IPCC report released in 2013 increased their predictions of SLR from 2007, with the higher-end “business as usual” model (current trend in emissions) at 52-98cm by 2100 (Church et al. 2013).

The change in sea levels detected around the planet are due to the increase in oceanic water volume, termed eustatic sea level rise (ESLR) and calculated as a global mean from a network of tidal gauges and satellite altimetry. Long term historical rates of change are determined through the averaging of tidal gauge measurements collected from across the planet, with the more recent and precise measures utilizing satellite altimetry data (Church and White 2011). Using the long term global tide gauge records with current satellite altimetry data, average SLR during the 20th century was found to be 1.7 ± 0.3 mm/year, increasing to 1.84 ± 0.19 mm/year from 1936-2001, and with satellite altimetry data during 1993-2009 increasing to 3.2 ± 0.4 mm/year (Church and White 2006, 2011, Meehl et al. 2007).

Two of the main factors responsible for increasing rates of SLR are the melting of permanent land ice and the thermal expansion of water already in the ocean (Church et al. 2011). These both increase the volume of water in the oceans and are influenced by the effects of climate change and the resulting rise in average global temperatures (Church et al. 2011). If one considers the ocean basin as a wash tub with the coastal regions with estuarine and other wetland buffers as the rim, the result of continued rise is the filling of our ocean basins and an overflowing of water onto on the rim.

The loss of land-covering ice has a large impact on rising sea levels, accounting for nearly half of the added volume in the ocean from 1993-2008 (Church et al. 2011). The extreme scenario would be a total melting of all the land covering ice, potentially increasing sea levels by as much as 65 meters, with most of that coming from the ice sheets in Greenland and West Antarctica (Bamber et al. 2001, Zhang et al. 2003). This dramatic increase would be the result of the direct input of a large volume of water into the ocean basins from the currently stored ice reserves in overland glaciers and ice sheets. More realistically, the average annual change over the last twenty years shows that the melting of those large ice reserves contributed around 1mm/year from the Greenland (≈ 0.9 mm/year) and Antarctic (≈ 0.1 mm/year) ice sheets and about 1mm/year from smaller continental glaciers and icecaps, indicating a trend toward the acceleration of melt rates over time, though there is a high degree of uncertainty from current lack of data about the thickness of ice reserves (Figures 1 and 2) (Cazenave and Llovel 2010, Meier et al. 2007).

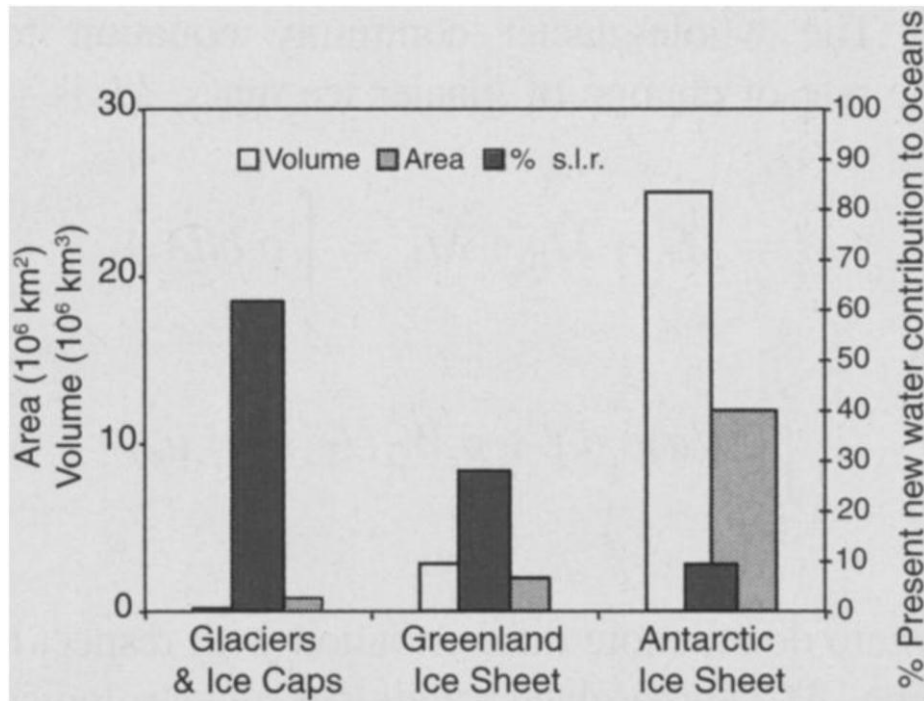


Figure 1. Contributions of land covering ice melt to sea level rise, indicating that the Antarctic area, with the most ice cover is not the largest contributor to SLR at this time (Meier et al. 2007).

The other key contributor to an increased rate of sea level rise around the world is the thermal expansion of seawater, accounting for most of the remaining observed rate of rise (Church et al. 2011). The input to oceanic volume from the warming of ocean water is the result of the high thermal conductivity of seawater (absorption of heat into the ocean), combined with increasing global temperatures associated with the buildup of greenhouse gases. It is estimated that in the last 10 years thermal expansion has increased in its total contribution to the rise in sea levels, inputting 1.6 ± 0.5 mm/year in the upper 3000 meters of water, with those predictions putting thermal expansion at about half of the ESLR currently observed (Figure 2) (Bindoff et al. 2007).

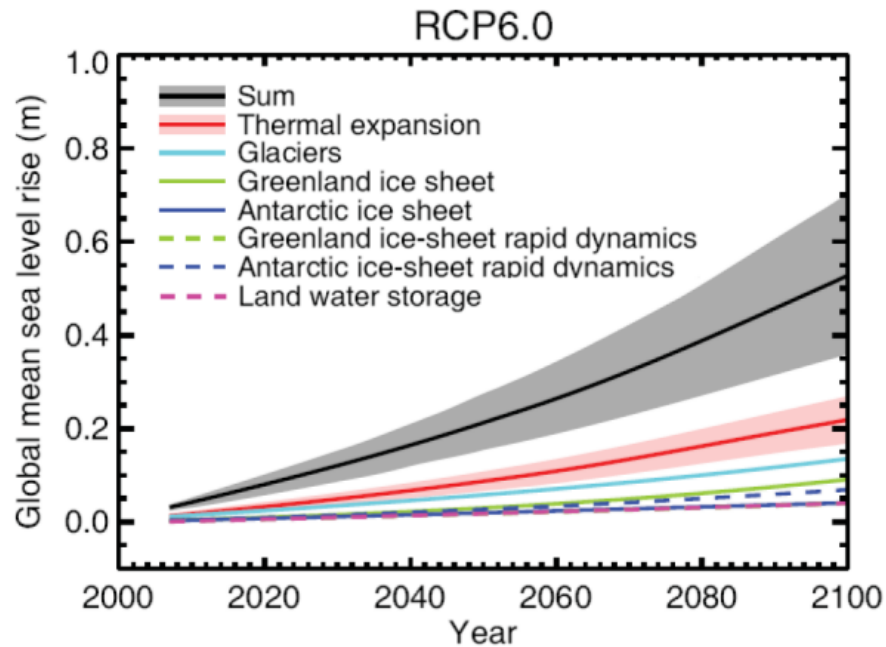


Figure 2. The total contribution to sea level rise as predicted from the IPCC 2013 intermediate sea level rise scenario, the beginning represents current rates (Church et al. 2013).

More localized geologic phenomena, such as vertical land movement from plate tectonics and isostatic rebound in formerly glaciated regions can have an effect on the perceived sea level rise at a given location (Church et al. 2004). On the Washington and Oregon coasts, tectonic processes associated with the Pacific subduction zone and the deformation of the continental plate causes changes in surface elevation at varying degrees across the region, which may reduce or increase the effects of rising sea levels (NRC 2012).

To predict the impact of sea level rise at the local level, the rate of relative sea level rise (RSLR) is used, taking ESLR and adjusting for localized geologic phenomena ($RSLR = ESLR \pm \text{vertical land movement}$), resulting in the effective rate of sea level rise observed at a given location. Due to the variability of processes associated with sea level rise, the observed rate at any location may drastically differ from the global average (Day et al. 2008). For instance, along the Pacific Coast of Washington, local rates of SLR have remained

relatively stationary since the 1980s, placing sea level rise measures on the coast and within the Puget Sound well below the GMSLR ($\approx 3\text{mm/year}$), at less than 2mm/year in some places (NOAA 2013). From 1930-1980, records show the rate of RSLR was on par with the global rate of mean sea level rise. This recent suppression of sea level rise is attributed to a shift in oceanic wind currents, with evidence of a change in those patterns that will increase rates along the Pacific Coast and potentially amplifying it beyond the global mean rate (Bromirski et al. 2011).

1.2.2 *Alteration of watersheds*

It is recognized that watersheds with hydrological impediments, such as those built for human development, experience greatly reduced sedimentation rates, resulting in the loss of the downstream habitat, including estuaries (Kunz 2011). The main method in which rivers are altered is the installation of dams and levees to regulate the flow of water and restrict channel movement and over bank flows (Hopkinson and Vallino 1995). These modifications to natural systems alter sediment delivery, causing much of the sediment once destined to the lower river and estuary to be entrapped or diverted (Shaffer et al. 2009).

The largest structures are dams, which regulate the downstream movement of water, often resulting in a reduction of flow below the structure and causing suspended sediment to settle out of the water column before continuing on through the dam, potentially starving the river and estuarine habitat downstream of sediment. Levees on the other hand are reinforced and raised banks, designed to hold back high water that would normally go over the banks and onto the floodplain from leaving the main channel, causing

increased in-channel flow during storms and the diversion of sediment from reaching beyond the banks of the river that would naturally occur during those events (Hopkinson and Day 1980a,b). Both dams and levees lead to decreased sediment deposition, altered flow regimes, and decreased flooding that negatively impact floodplain and estuarine habitat downstream, increasing the effects of erosional processes in some places, and causing areas that were once building sediment stores, such as an estuary to gradually erode away and become submerged over time (Yang et al. 2007).

1.2.3 Accretion, subsidence, and equilibrium

A key factor to the continued persistence of estuaries under increasing sea levels is a rate of surface elevation gain that is equal to or greater than that of the rising sea (Lovelock et al. 2011). The deposition or accretion of sediment is the main method in which estuaries gain surface elevation. This is the vertical accumulation of material at the surface, often from the settling of suspended organic and mineral material, also through the production of organic material in place from estuarine vegetation (Reed 1995). More conservative estimates show that it would require average accretion rates in estuaries around the world of 1.8mm/year and up to 5.9mm/year to keep pace with the predicted changes in global sea levels over the next century, with some more extreme models pushing as high as 1cm/year averaged over the next century (Lovelock et al. 2011).

Historically, wetlands have been shown to maintain equilibrium with changing sea levels by the accretion of sediments and/or buildup of biomass from estuarine vegetation (Morris et al. 2002, Redfield 1972). However, over the last century, an acceleration of sea level rise and decreased sediment inputs from modified river systems has tipped this

equilibrium out of balance, with many estuaries across the world losing elevation at rates higher than the rising sea levels (Syvitski et al. 2009). Though research has shown that some estuaries have been able to respond to the current higher rates of sea level rise through increased sediment deposition where inundation is taking place in tidal marshes and mangroves, this is not always the case in such circumstances, with many more examples of loss (Reed 1995).

1.2.4 *Role of vegetation in sediment dynamics*

A major component of the ecological valuation of a system is the amount of primary productivity that occurs in the area (Batker et al. 2008). The productivity of a system is determined by assessing the amount of usable energy that the primary producers store during a growing season, termed as the net primary productivity (NPP). Productivity measures such as NPP do not include all of the energy created in a system, leaving out the difficult to quantify energy that has already been consumed for the maintenance of the system and biomass (roots) found below the soil surface. Even without the total measure, the above ground energy available is useful in assessing and comparing the ecological function and health of areas and is important in restoration efforts, as the goal is often the return to a sustainable natural state (Costanza and Mageau 1999).

The presence of healthy estuarine vegetation communities is essential to the sustainability of the system, with vegetation presence linked to increased sediment deposition. This is achieved through the attenuation of water flow and the entrapment of material on the stems and leaves of standing growth (Li and Yang 2009). The decaying plant material from the previous growing seasons is also linked to increased surface elevation

gain, through direct input of organic matter onto the surface (Reed 1995). These processes require the presence of productive species adapted to tolerate frequent flooding and high salinities. In areas impacted by human modification, those species are often not present in their natural abundances, resulting from a loss of habitable area from human modification, an example being built levees for farmland reclamation.

1.2.4.1 Vegetation communities

Freshwater vegetation, such as those found inside farmlands that have been leveed during reclamation projects, have been shown to have a lower stress tolerance compared to estuarine types, and may be reduced when exposed to the higher stresses of tidal flow (Cui et al. 2011). A transition should take place in restored areas when saltwater and more frequent flooding regimes return with tidal flows. The more competitive and less stress tolerant freshwater vegetation will be reduced, with the physiologically stress adapted species having the advantage in areas with reintroduced tidal flow, shifting the community structure toward a greater abundance of estuarine vegetation (Crain et al. 2004). Support for this hypothesis has been demonstrated in studies indicating that a limiting factor on vegetation in saltwater environments is stress tolerance, such as flooding and salinity tolerance, whereas in freshwater areas competition is the main driver of vegetation distribution (Gou and Pennings 2012). It is also been shown that the abiotic factors driving plant communities in an estuary can differ between elevations, with salinity and flood frequency having different effects between low and high elevations, resulting in change to community structure with elevation gain or loss (CUI et al. 2011).

1.3 Study Area

1.3.1 *Puget Sound*

The Puget Sound is located in western Washington and consists of a deep glacially scoured basin with many fjords, formed during the previous ice age, 13-15 ka years ago (Booth 1994, Emmet et. al 2000). The shorelines in the region are characterized by steep cliffs with narrow beaches below and quick drops to deep water depths. Estuaries within the Puget Sound are often located within river deltas that provide low elevation reliefs on their floodplains, which are essential for the formation of those intertidal habitats. Since European settlement of the Puget Sound, as much as 82% of wetland surface area within the basin has been lost due to human modification and development (Batker et al. 2008).

1.3.2 *Port Susan Bay*

Port Susan Bay is located at the transition of the Stillaguamish River into the northern part of the Puget Sound. The Stillaguamish River has no major hydrological impediments such as large dams to impede sediment, though there is a small diversion dam five miles from the mouth of the river that redirects some flow through a side channel for agricultural use. The Nature Conservancy purchased the Port Susan Bay Preserve in 2001, located approximately two miles south of Stanwood, WA, on the Stillaguamish River Delta. The preserve comprises 1,668 hectares of mostly intact intertidal wetlands, with 65 hectares of leveed farmland designated for restoration (Marine Conservation 2012). The farmland site is located just north of Hat Slough, at the mouth of the Stillaguamish River (Figure 3). Through many years of farming since reclamation of the land, oxidation and compaction of the soil have occurred within the farmed area, causing soil elevations inside

the levees to fall below that of the surrounding estuary, creating an imbalance of sediment with the adjacent estuary, decreasing the agricultural value due to difficulty with drainage and salt water intrusion (Puget Sound 2011, Verhoeven et al. 2010) (Figure 3). LIDAR imaging shows the lower regions of the farmland at around 1.8 meters above sea level, with the high marsh directly on the other side of the levees at around 2.5 meters (Figure 4).

The tidal estuarine wetland communities within the Port Susan Bay estuary include eelgrass and estuarine emergent marsh. The vegetative community structure of interest in this study and the target of The Nature Conservancy's restoration project is the emergent estuarine marsh. The adjacent oligohaline (scrub-shrub) estuarine marsh that occurs at higher elevations east of this study area, have been almost completely eliminated by the presence of river and sea dikes.

The Nature Conservancy's restoration plans involves ongoing monitoring of vegetation, long-term measuring of sediment surface elevations, treatment of invasive plant species, that encompasses a larger project of the removal of outer levees between the farmland and the surrounding estuary. This will reintroduce tidal processes into the farm area, returning that area to an estuarine environment. The removal began in the spring of 2012, with breaching and removal of the outer levee completed in September of 2012. Along with the construction phase of the levee removal restoration, the project includes long term monitoring plans. Returning tidal function at the site will provide increased sediment and nutrient transport and deposition of material from the river into rest the estuary, as the estuary will have a greater area for additional distributary channel formation

and therefore having less energy in the outgoing water flow, increasing sediment deposition from the river before entering the open bay (Syvitski et al. 2005).

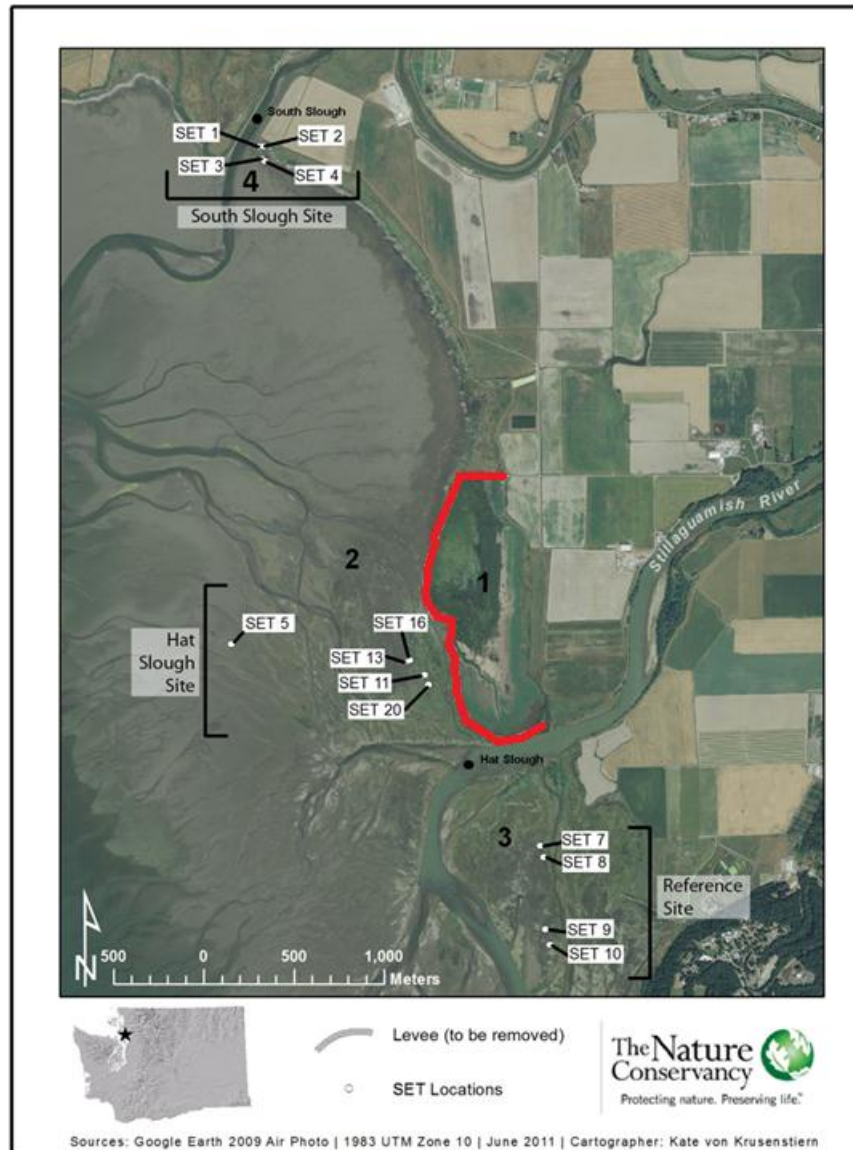


Figure 3. Port Susan Bay and the restoration area, located about 60 miles north of Seattle, WA in the northern Puget Sound, Washington. Zone 1 is the old farmland known as the restoration area with the surrounding levee represented as the red line. Zone 2 is the area directly outside the leveed farmland (Hat Slough). Zone 3 is the reference site across the river channel and historically less affected by levees. Zone 4 is the north area, beyond the influence of the restoration project and fed by a small distributary (South Slough).

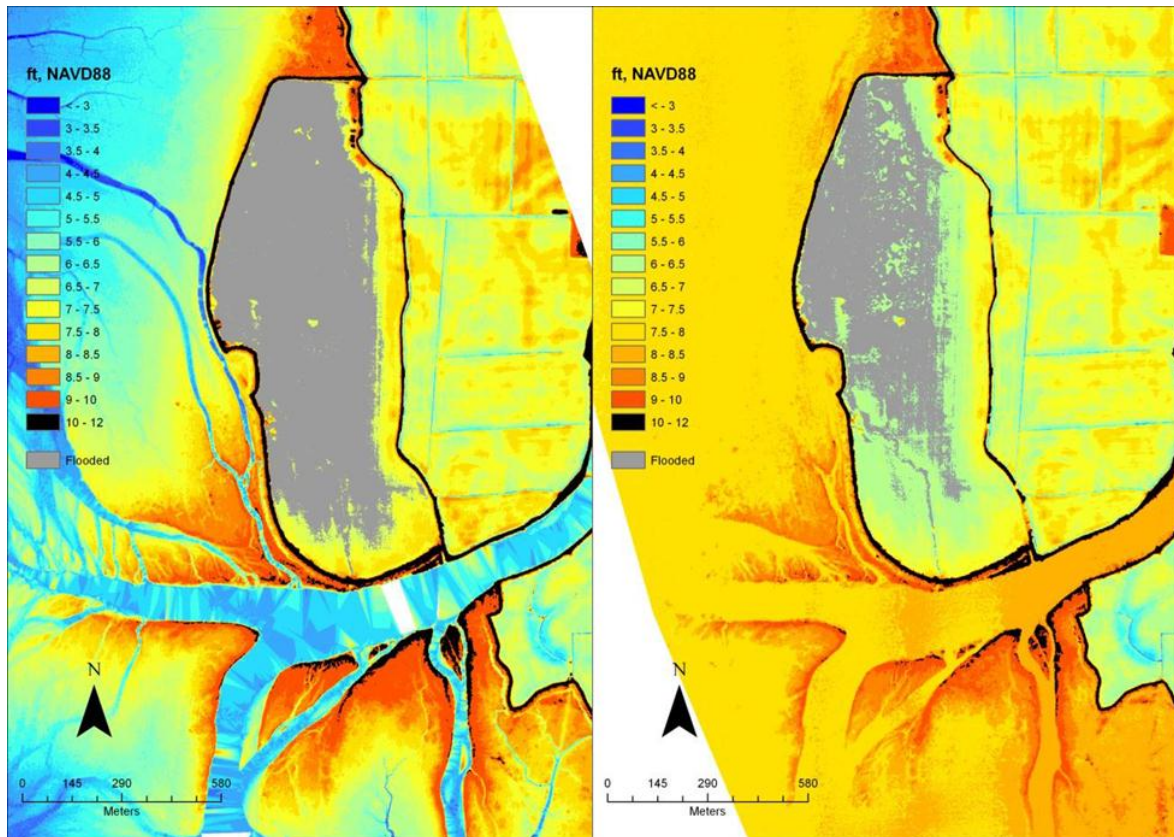


Figure 4. LIDAR elevation images indicating the surface elevations within the restoration and outside areas. The hot colors (red) indicate high elevations, the cooler (blue) indicate lower elevations. The image on the left (a) shows the estuary during low tide, but with the farmland inundated with water. The right image (b) shows the farmland with less water cover, but at high tide. Both images utilize the same key and can be directly compared. Figure courtesy of Hood (2011).

2 ESTUARINE SURFACE ELEVATION DYNAMICS

2.1 Objectives

The main objectives of my research were to quantify the current trends in surface elevation change and vegetation community structure in the PSB estuary. I used physical (elevation and accretion) and biological (peak biomass) factors that have been shown to correlate with sediment surface dynamics to explore the relationship with elevation, productivity, and surface elevation processes in PSB. The goal of my work was to determine if the system is sustainable under increasing global mean sea level rise (GMSLR). The results

of my work on this project could be used to gauge the current sustainability of the PSB system and help guide further restoration and monitoring work in the area.

Hypotheses:

1. The Stillaguamish River is relatively unmodified, so that the estuary in Port Susan Bay has sufficient sediment inputs to maintain equilibrium with the current rate of sea level rise within the Puget Sound.
2. Sites within the estuary at higher elevations will have more primary productivity (NPP) than lower elevation sites, due to decreased frequency of tidal stress on the vegetation at higher elevations.
3. Sites with high productivity will have more sediment accretion compared to low productivity sites, due to the ability of vegetation to entrap material, and therefore sites with higher productivity will have more surface elevation gain than lower productivity sites.

2.2 Methods

2.2.1 Elevation change

The change in sediment surface elevation over time is measured using the surface elevation table (SET) (Cahoon et al. 2002) (Figure 5). Each SET unit consists of two parts, a stationary stainless steel rod providing a stable benchmark and a portable measuring device that attaches to the rod. The stainless steel rod is installed by driving connectable 1.3 meter sections vertically into the substrate until the point of refusal, usually between 5 to 7 meters in depth. At that depth it is assumed that the unit is deeper than the processes of shallow subsidence, such as organic matter decomposition and soil compaction. Further

stability is achieved by affixing a cement collar to the pin to a depth of about 15cm, placing the cement collar just below the surrounding soil surface to avoid scour. Finally a permanent metal collar with direction markers is affixed to the top of the pin for attachment of the portable SET measuring device.

To prevent disturbance of the sampling area, only 4 of 8 possible sampling directions on the collar of the rod were used, those points are the 4 seaward directions at Port Susan Bay. Outward towards the bay of those sampling points from the rod is referred to as the “infield” and disturbance should be minimized to insure accuracy. Disturbance of the substrate there would mean the loss of those data points for at least that sample year. Once properly situated at the pin, the SET device is attached to the collar using clamps and leveled in all dimensions with a bubble level and adjustment screws. After leveling, 9 quarter inch diameter fiber glass pins are lowered to the substrate surface through holes in the leveled SET arm and secured with clamps. The portion of the pins that are showing above the SET arm is then measured, subsidence and soil erosion will yield shorter pin measurements and accretion of sediment will lengthen the exposed portion of the pins from the previous measurements. Controlled testing has shown that these methods yield accurate and repeatable measurements to within 1.5mm (Cahoon et al. 2002).

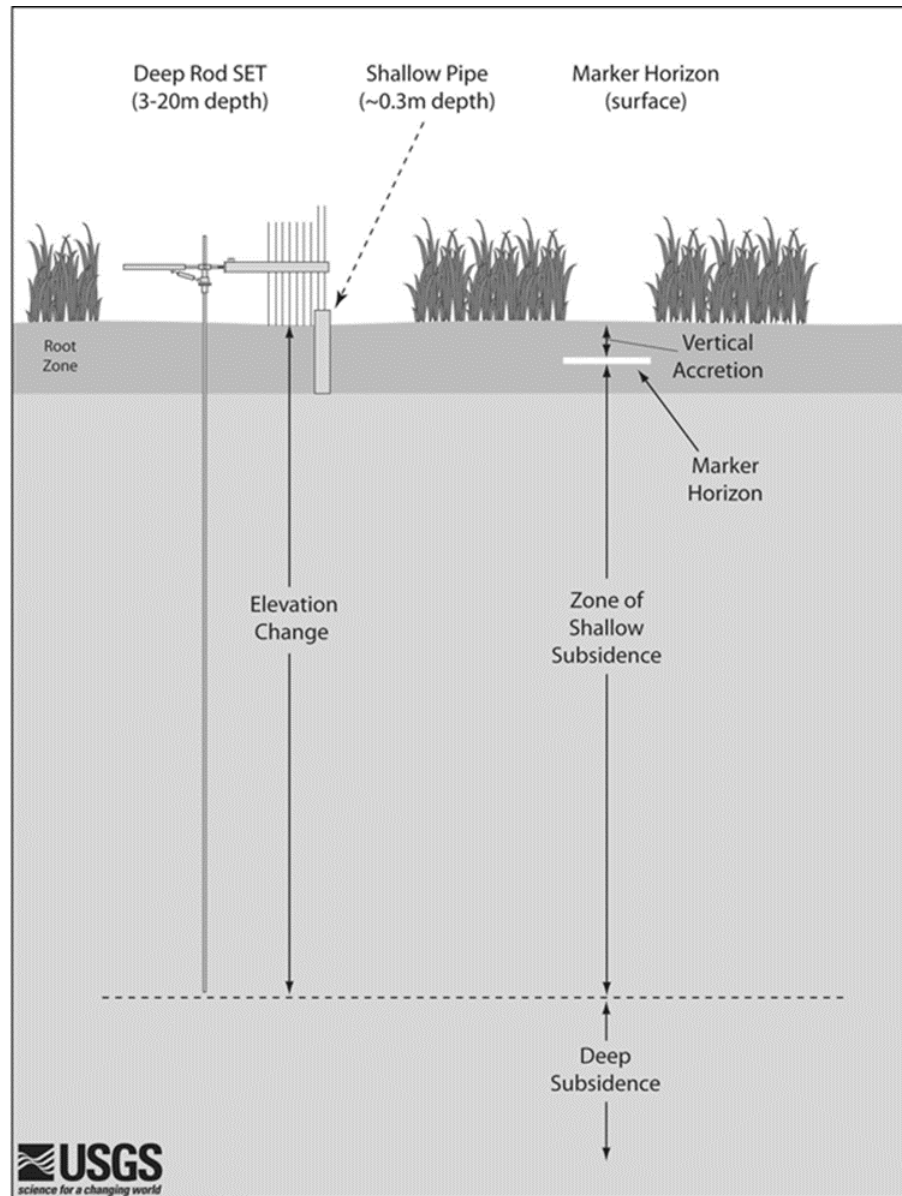


Figure 5. Measurements of the surface elevation are made using sediment surface elevation tables (SETs), shown left. SETs integrate all shallow surface processes into a single measure of elevation change (depositional and erosional). Elevation change below the depth of the SET rod are considered geologic processes and beyond the scope of the device. Feldspar Marker horizons are used to quantify sediment deposition, by measuring material deposition on top of the placed white clay horizon, pictured right. Figure courtesy of USGS Patuxent Wildlife Research Center (2013).

In the spring of 2011, a total 13 SETs were installed at 4 locations throughout the preserve, 4 at South Slough, 4 at Hat Slough, 4 at the reference site to the south of Hat Slough, and 1 out on the bare tidal flat (Figure 3). Locations were selected to monitor the influence of the levee removal across the preserve, with the outside location at Hat Slough adjacent to the farmland and directly affected by the restoration work, the north location at South Slough still being influenced by remaining levees, and the reference location to the south that was not impacted by levees. No SETs were installed inside the restoration site due to the lack of access and heavy equipment disturbance during the construction phase of the levee removal. The purpose of the SETs is to monitor surface elevation change before, during, and many years after the restoration process. Each location, excluding the bare tide flat, had SETs installed on what was delineated as high and low marsh site types; vegetation and elevation being determinates of the designation. The low marsh sites contained more of the American bulrush (*Schoenoplectus americanus*) with a distinct change to more grasses and rushes in the high marsh. At each site type, high or low marsh, two replicate SETs were installed, this replication allows for comparison and sampling of the area even if a SET is lost to scour, debris, or other unforeseen circumstances. Sampling of the SETs takes place during the summer field season, when the weather and tidal cycles allow for regular daytime sampling, usually early and late summer. After installation surface elevations (NAVD88_m) at the SETs were measured by the US Geological Survey (USGS) using Real Time Kinetic Global Positioning System (RTK-GPS) equipment during the summer of 2012.

2.2.2 *Sediment accretion*

Along with the SETs, three feldspar marker horizons were installed at each SET location. When combined with the SET measurements, we can measure not only the changes in surface elevation, but also the shallow surface processes (subsidence) that may contribute to those changes. In most cases white feldspar clay is used to mark the sediment surface, as more sediment accretes, the feldspar will become buried, leaving a white band below the newly deposited sediment. This white band is located by removing a sediment plug from the area and measuring the newly deposited sediments above the feldspar marker. In locations such as the bare tide flat, the low elevation, lack of vegetation, and highly erosive macro-tidal nature of the area makes feldspar markers unviable.

For those areas of higher potential sediment transport, a section of 1cm² gridded plastic fluorescent light cover is pressed into the surface until level. The plastic gridding is less likely to be washed away by tidal processes, but may not be installable in vegetated areas. Sampling is done by pressing a ruler down into the soil until contacting the grid, the length of ruler within the substrate is the accretion. Both the feldspar and plastic gridding, when paired with an SET, can help explain the processes behind changes in the surface elevation, such as shallow subsidence and sediment accretion or erosion (tidalmarsh 2012). Marker horizons are placed in a diamond pattern at each SET location, much like the bases on a baseball field, home plate being the SET pin. Locations of the marker horizons were staked with two white 1 inch PVC tubes at opposite corners for location purposes. The stakes served to also delineate the “infield” at each SET site, helping locate the pins and preventing accidental disturbance of the sampling surface (Figure 6).

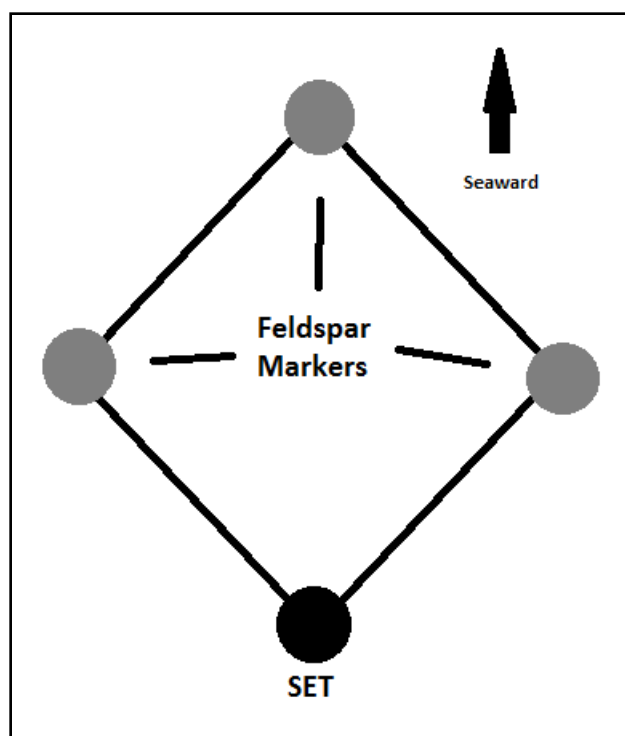


Figure 6. Diagram of the diamond patterned “infield” area for installing the SETs and feldspar markers together. The area inside of the diamond is off limits to prevent disturbance of the measured substrate.

2.2.3 Primary Productivity

At each of the SET sites, three vegetation plots were selected and harvested to determine the annual net primary productivity (NPP) across the sampling sites. Sampling was conducted during peak biomass in the late summer from August to September. Three plots were randomly selected from the SET location, with plot selection based on blind tosses of a .25m² quadrat in the area not considered off limits due to the SET and feldspar markers. To measure the NPP at the plots, all vegetation rooted from outside the perimeter of the plots were excluded from the area and vegetation within the plot was harvested by clipping all growth at the soil level, storing them in labeled and sealed bags (Malone 1968). In the lab, each clip plot sample had the dead vegetation removed from the previous year and the living samples were then sorted by species and stored in individually labeled paper

bags for drying. The bagged samples were placed into the drying oven at 70° Celsius for one week, removing all moisture from the samples. The dried samples were removed from the storage bags and immediately weighed on a Mettler PC 2000 digital scale.

2.2.4 Data analysis

2.2.4.1 Rate of surface elevation change

The rate of change in sediment surface elevation was calculated by comparing yearly SET pin heights to the baseline established a few months after installation, giving time for the surface to recover from the disturbance caused by the SET installation. Mean pin lengths were used, determined at each SET site by calculating the average pin height for the entire device (n=36), yielding a single mean elevation change per year at each SET. The purpose of using a mean of all 36 pins per SET is to avoid pseudo-replication, as the experimental independence of the four SET arms is disputable due to being located on the same SET rod.

2.2.4.2 Rate of sediment accretion

Multiple feldspar depths were measured at the three “bases” installed at each respective SET site. Those depths were averaged to yield a mean feldspar depth for each SET site. The mean yearly accretion rates were calculated by dividing the total marker depth by the time since installation.

2.2.4.3 Shallow surface subsidence

The contribution of shallow surface processes to the sediment surface elevation was determined by taking the rate of surface elevation change at the SETs and subtracting the rate of the accretion found at the nearby feldspar markers (shallow surface processes =

surface elevation change – accretion). The left over elevation change after accretion measures are removed is from below surface processes.

2.2.4.4 Surface elevation deficit/surplus

The yearly deficit in surface elevation was determined by taking the change in surface elevation and subtracting the rate of RSLR and ELSR (elevation deficit = surface elevation change – SLR). Surface elevation tables (SETs) were used to determine the change in surface elevations. The RSLR of an area can be determined with the current rate of ELSR (1.8-3.2mm/year) and factoring in local vertical land movement (a loss of 1.6 mm/year), placing the rate of RSLR as calculated from the global mean at 3.4-4.8mm/year in Port Susan Bay (Church and White 2006, 2011, NOAA 2013). Another method is using nearby tidal gauge stations to track the local sea level rise. The nearest station in Port Townsend, WA shows that the measured rate of RSLR is lower than that calculated from the global mean, with the actual rate of RSLR in the area at 1.98mm/year from about 1972-2006.

2.2.4.5 Location and marsh type influence on surface elevation

To determine if the location (north, south, reference) and marsh type (high and low) of the SET sites had an effect on the mean yearly rate of surface elevation change, a 3x2 analysis of variance (ANOVA) was used to test for significant effects of those factors on the rate surface elevation change: $Y(\text{elevation change})_{ijk} = \mu + (\text{location})_i + (\text{marsh type})_j + (\text{location} \times \text{marsh type})_{ij} + \varepsilon_{ijk}$. The statistical software package SPSS was used for this analysis.

2.2.4.6 Primary productivity

For the purpose of displaying and interpreting productivity at each location and marsh type, the mean NPP of the two replicates and a total mean by marsh type were used. During statistical analysis, all plots were kept as separate experimental units.

2.2.4.7 Location and marsh type influence on primary productivity

To determine if the location (north, south, reference) and marsh type (high and low) of the SET sites had an effect on the annual peak biomass (NPP) in 2012, a 3x2 analysis of variance (ANOVA) was used to test for significant effects of those factors on NPP:

$$Y(NPP)_{ijk} = \mu + (location)_i + (marsh\ type)_j + (location \times marsh\ type)_{ij} + \varepsilon_{ijk}.$$

The statistical software package SPSS was used for this analysis.

2.2.4.8 Physical and biological variance in surface elevation change

I utilized Pearson's R to explore correlations between the measured physical (mean elevation change, mean accretion rate, mean shallow subsidence, and elevation) and biological (NPP) variables across the preserve. Variables were tested for normality to meet the correlation assumption. I removed outliers in the data if present, outliers were determined through Q-Q and box plots. Any correlation between mean elevation change, mean accretion rate or mean shallow subsidence will be ignored due to their non-independence. To visually examine the relationship between significant correlations found in the analysis, I created a plot of the two variables, and then applied a linear trend line to the plot to determine the direction of the significance. The statistical software package SPSS was used for this analysis.

2.3 Results

2.3.1 Sampling problems

2.3.1.1 Surface elevation

Three attempts at sampling SET location 20 were unsuccessful due to dense vegetation and root structures forming at and around the SET sampling points, the corresponding SET location 11 was measurable, demonstrating the usefulness of replicate sites. During the third sampling year in late spring of 2013, a large section of drift wood was found wedged against the SET 20, likely rendering the SET unusable in the future. Due to the inability to sample SET 20 during all attempts, the SET location will be excluded from analysis for this short term project.

During the 2012 sampling year, a sampling error of 3mm was introduced at an unknown time through a defective ruler. This error would lower the surface elevation recorded in the data by 3mm and affects an unidentified number of SETs. Due to this, the significance of surface elevations may be underestimated for the 2012 sampling year. For this reason, data from the 2012 sample year is excluded from further analysis. A yearly average rate of change for both years is used instead, determined from the total elevation change from the baseline in 2011 to the last sample date in 2013 and divided by the time in years from the baseline to last sampling.

2.3.1.2 Marker horizons

In the summer of 2012 SET site 5 on the bare tidal flat could not be sampled for accretion, due to erosion of the plastic gridding. Sampling in 2013 of the marker horizons at sites 13 and 16 directly outside of the restoration area were not possible due to a soft

muddy substrate making the feldspar marker unrecoverable at the time of sampling.

Measuring the marker depth at the bare tidal flat was not possible do to the exposure of the installed plastic gridding, though still indicating erosional processes at the site (Figure 7).



Figure 7. The gridded plastic markers in the bare tidal flat were eroded, exposing the markers and not allowing for the sampling of accretion in that area.

2.3.2 Rate of surface elevation change

The mean rate of surface elevation change throughout the preserve was 0.43 ± 0.45 cm/year (± 1 standard deviation), elevation change ranged from -0.51 to 1.05 cm/year (Table 1). The north high marsh sites are gaining elevation (SET 1 = 0.55mm/year, SET 2 = 0.7mm/year). The north low marsh sites are losing surface elevation (SET 3 = -0.2mm/year, SET 4 = -0.12mm/year), with evidence of erosion found nearby in terracing of the sediment bank between the high and low marsh areas. The reference high marsh sites are gaining elevation (SET 7 = 1.06mm/year, SET 8 = 0.72mm/year). The reference low march sites are gaining elevation (SET 9 = 0.43mm/year, SET 10 = 0.8mm/year). The outside high marsh site

(SET 11) showed no substantial change in elevation. The outside low marsh sites have the highest elevation gain in the preserve (SET 13 = 1.09mm/year, SET 16 = 0.77mm/year).

Overall, 8 of the 11 sampled SETs are indicating positive sediment surface elevation gain (Figure 8, Table 1).

SET #	Location	Type	Location LAT/LON	Elevation (meters)	Pin Avg 2012 (cm)	Pin Avg 2013 (cm)	Mean Yearly Rate (cm)	Baseline Sample	Last Sample
1	North	HE	N48°13'37.2" W122°23'01.3"	2.66	0.47	0.93	0.55	8/26/2011	4/29/2013
2	North	HE	N48°13'36.9" W122°23'00.1"	2.73	0.71	1.17	0.70	8/26/2011	4/29/2013
3	North	LE	N48°13'34.9" W122°23'00.5"	1.82	0.17	-0.34	-0.20	8/26/2011	4/29/2013
4	North	LE	N48°13'34.5" W122°22'59.7"	1.85	0.05	-0.21	-0.12	8/26/2011	4/29/2013
5	Mud	UT	N48°12'07.8" W122°23'09.9"	1.50	-1.42	NA	NA	8/26/2011	8/1/2012
7	Ref	HE	N48°11'31.2" W122°21'47.3"	2.40	1.18	1.90	1.06	9/9/2011	6/26/2013
8	Ref	HE	N48°11'29.1" W122°21'46.2"	2.39	0.68	1.31	0.72	9/9/2011	6/26/2013
9	Ref	LE	N48°11'16.1" W122°21'46.2"	2.01	0.29	0.78	0.43	9/9/2011	6/26/2013
10	Ref	LE	N48°11'13.3" W122°21'45.0"	1.99	1.06	1.44	0.80	9/9/2011	6/26/2013
11	Out	HE	N48°12'02.2" W122°22'18.0"	2.63	-0.87	-0.06	-0.04	8/26/2011	5/27/2013
13	Out	LE	N48°12'04.5" W122°22'22.4"	2.22	1.41	1.93	1.09	8/26/2011	5/27/2013
16	Out	LE	N48°12'04.7" W122°22'22.1"	2.21	0.29	1.35	0.77	8/26/2011	5/27/2013
20	Out	HE	N48°12'00.2" W122°22'17.0"	2.55	NA	NA	NA	8/26/2011	5/27/2013

Table 1. Average yearly SET surface elevation change, with the mean yearly change calculated from the total change in 2013. NA indicates sites that were not sampled that year, either due to obstructions on the surface or lack of available time to sample. Site locations, marsh type, coordinates are displayed, and sample dates are displayed. HE = high elevation marsh, LE = low elevation marsh, and UT = unvegetated tide flat. Data from 2012 was not used in analysis, due to sampling error of 3mm at unknown number of SETs.

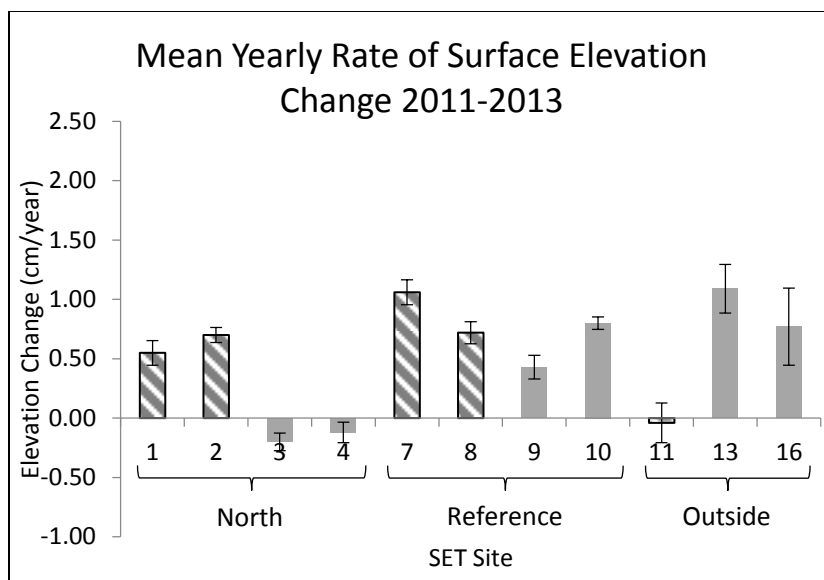


Figure 8. Mean yearly rate of sediment surface elevation change with standard error displayed. Striped bars represent high marsh sites and solid bars are low marsh sites. Sites 1-4 are the north sites, 7-10 are the reference sites, and 10-16 are the outside sites.

2.3.3 Rate of sediment accretion

Marker horizon measurements in 2012 show positive accretion rates as most sites, with a high level of variability in those rates of accretion between most replicates and across the three locations within the preserve (Figure 9). In 11 of the 12 sites, a substantial amount of sediment accretion, change greater than the standard error, were seen since installation of the markers. Those rates of accretion range from about 0.25 to over 2 cm/year, with a mean rate of sediment accretion across the preserve of 0.73 ± 0.59 cm/year (± 1 standard deviation). At SET 3 in the north area, evidence of surface erosion was seen through the partial exposure of the plastic marker gridding installed at that site, resulting in an average loss at that site of -0.14 cm/year ± 1.21 cm/year (± 1 standard deviation) (Figure 9).

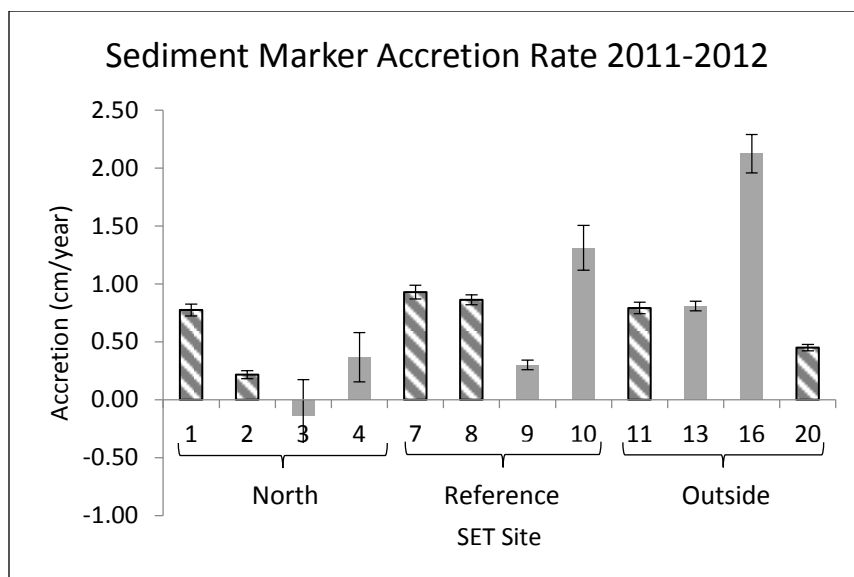


Figure 9. This is the first year of sampling after installation of the feldspar markers with standard error displayed. The trends are of accretion at most sites, with a wide variance in rates. Striped bars represent high marsh sites and solid bars are low marsh sites. Sites 1-4 are the north sites, 7-10 are the reference sites, and 10-16 are the outside sites.

The marker horizons, when measured in 2013, indicated more consistent rates of accretion across the preserve compared to the previous year, with accretion rates at 6 of the 10 sites between .21 and 0.7 cm/year, 2 sites show minimal change (SETs 10 and 11), with one site showing a loss (SET 4), yielding a mean rate of accretion across the preserve at 0.23 ± 0.30 cm/year (± 1 standard deviation) (Figures 10 and 11). In 2013, SET 3 indicated possible accretion of 0.21 ± 1.43 cm/year (± 1 standard deviation), though with standard error greater than the change, that gain should not be considered substantial. SET 4, which accreted sediment in 2012, shows a loss of surface sediment in 2013, at -0.15 ± 0.57 cm/year (± 1 standard deviation) (Figure 10). The total accretion over the sampling years and the calculated mean rate from it, indicates accretion at all of the SET sites, though sites 3 and 4 are far below the other sites in accretion rates and have sampling errors that are greater than the total change (Figures 11 and 12).

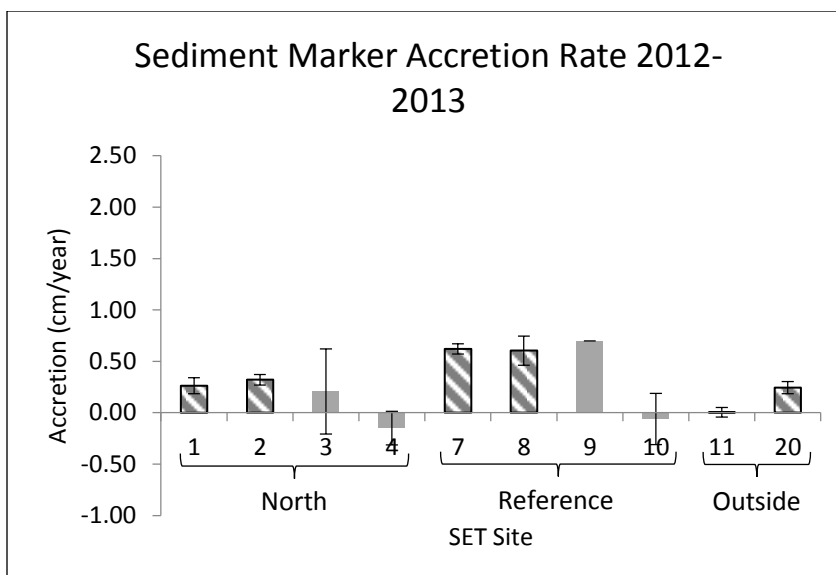


Figure 10. Rate of change from 2012-13 (2013 ROC=2013 depth-2012 depth) with standard error from 2013 depths. Striped bars represent high marsh sites and solid bars are low marsh sites. Sites 1-4 are the north sites, 7-10 are the reference sites, and 10-16 are the outside levee sites.

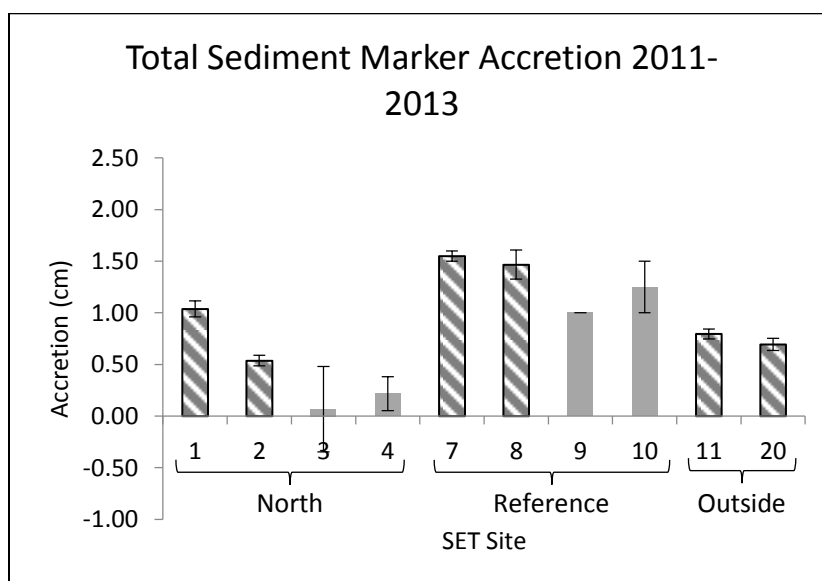


Figure 11. Total feldspar marker depth as measured in 2013 with standard error displayed. Striped bars represent high marsh sites and solid bars are low marsh sites. Sites 1-4 are the north sites, 7-10 are the reference sites, and 10-16 are the outside sites.

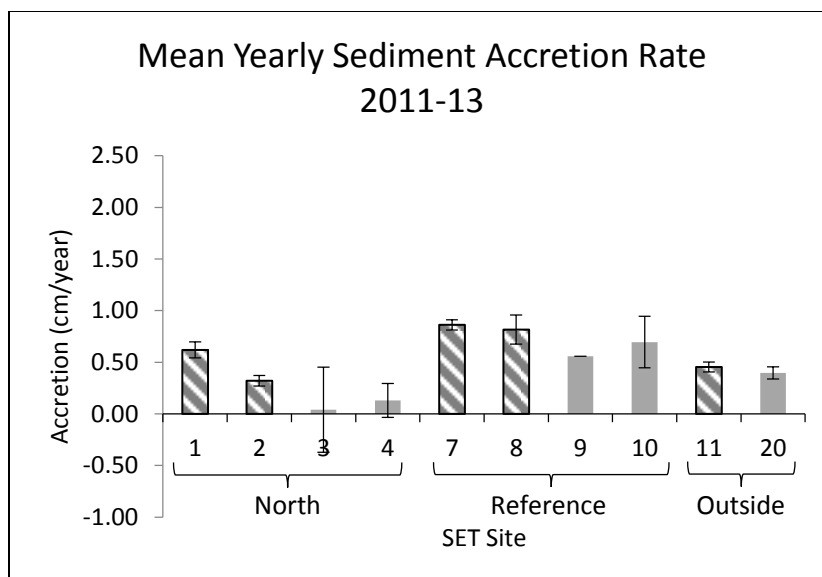


Figure 12. Mean yearly rate of accretion for all SETs sampled during both years with standard error from 2013 marker sampling displayed. Striped bars represent high marsh sites and solid bars are low marsh sites. Sites 1-4 are the north sites, 7-10 are the reference sites, and 10-16 are the outside sites.

2.3.4 Shallow surface subsidence

Shallow surface processes (elevation change – accretion) indicates subsidence of the soil in the preserve ranging from -0.07 to -0.49cm per year, with a considerably higher rate of subsidence at SET site 11. Three of the ten sites (SETs 2, 7 and 10) are indicating a gain of elevation from shallow surface processes, from 0.1 to 0.38cm per year (Figure 13).

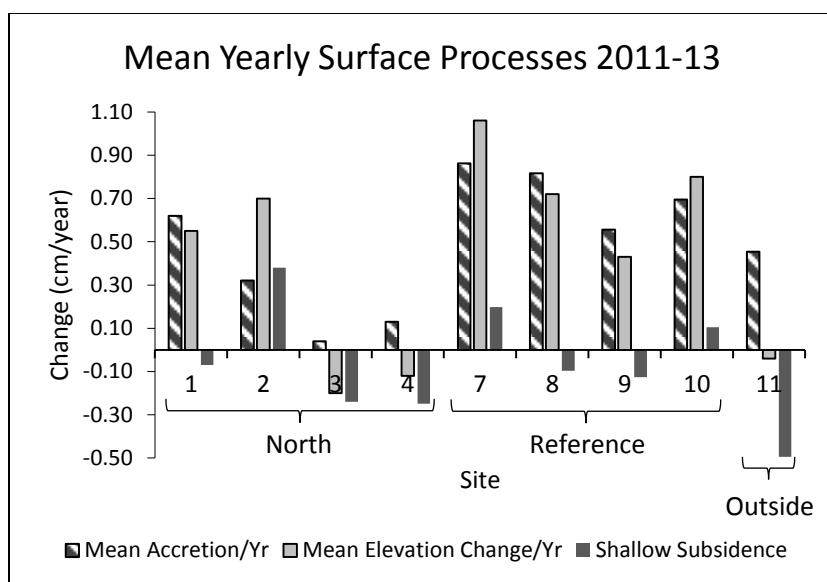


Figure 13. Mean yearly shallow surface processes from 2011-2013. Striped bars represent the total mean accretion rate, light grey is total mean elevation change, and dark grey is total shallow subsidence (elevation change – accretion). Sites 1-2 (Low) and 3-4 (High) are the north sites, 7-8 (High) 9-10 (Low) are the reference sites, and 11 (Low) is an outside site.

2.3.5 Surface elevation deficit

The surface elevation change, after factoring in the RSLR in the Puget Sound (1.98mm/year), indicates elevation gains well above sea level rise at most of the sites, from 2.3 to 8.9mm/year. Only three sites are showing a deficit in elevation, the two low marsh sites in the north location (SETs 3 and 4) have a deficit of 3.18mm/year (SET 3) and 3.98mm/year (SET 4), and a high marsh site outside the restoration area (SET 11) has a deficit of 2.38mm/year (Figure 14). At the low end of the global mean sea level rise (GMSLR), at 3mm per year, most sites still indicate gains in surface elevation above sea level, gaining from 1.3 to 7.9mm/year in elevation. The three sites showing a surface deficit under GMSLR are the low marsh sites to the north at 4.2mm/year (SET 3) and 5mm/year (SET 4), with the high marsh site outside the restoration area at 3.4mm/year (SET 11) (Figure 15).

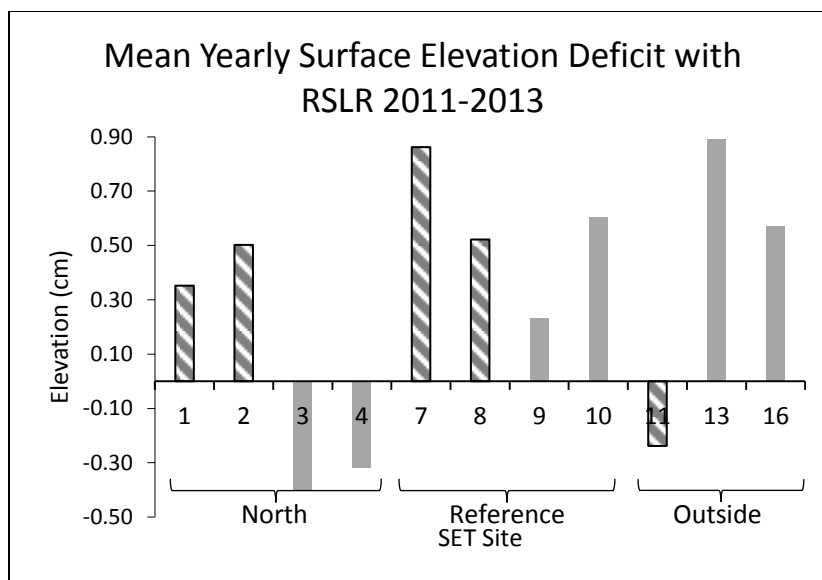


Figure 14. Mean yearly sediment surface deficit/surplus under RSLR (1.98mm/year). This is indicating that most of the preserve is has a yearly elevation surplus under current rates of RSLR. This also shows that the north low marsh areas and outer levee high marsh areas are losing elevation under current conditions. Striped bars represent high marsh sites and solid bars are low marsh sites. Sites 1-4 are the north sites, 7-10 are the reference sites, and 10-16 are the sites in the outside location.

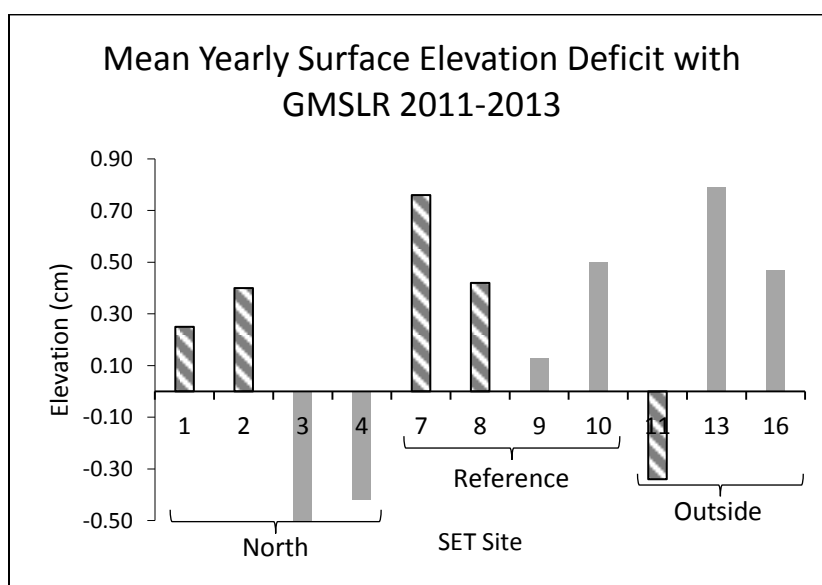


Figure 15. Mean yearly sediment surface deficit under global mean sea level rise (GMSLR) (3mm/year). This indicates that most of the preserve will have a yearly elevation surplus under the potential rate of sea level rise. This also shows that the north low marsh areas and outer levee high marsh areas will be lost at a more advanced rate. Striped bars represent high marsh sites and solid bars are low marsh sites. Sites 1-4 are the north sites, 7-10 are the reference sites, and 10-16 are the outside sites.

2.3.6 Location and marsh type influence on surface elevation change

The location of the SETs has a significant influence on the rate of surface elevation change found at each site, indicating conditions are more similar within a location than between all locations ($p < 0.05$) (Figure 8 and 16). The location (north, reference, and outside) and marsh type (low and high) interaction significantly influences the mean rate of change in surface elevation at each site, so that location is a significant driver of the rate of surface elevation, but the effect varies by the marsh type ($p < 0.05$) (Figure 8, Table 2). It should be noted that the marsh type alone was not a significant factor on the rates of elevation change ($p = 0.86$).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Location	.542	2	.271	7.711	.042
Marsh type	.001	1	.001	.035	.861
Location * Marsh type	1.232	2	.616	17.517	.011
Error	.141	4	.035		
Corrected Total	2.013	9			

Table 2. Two-factor ANOVA of location and marsh type effect on the yearly mean sediment surface elevation change, indicating a significant interaction of location and marsh type on the rate of surface elevation change.

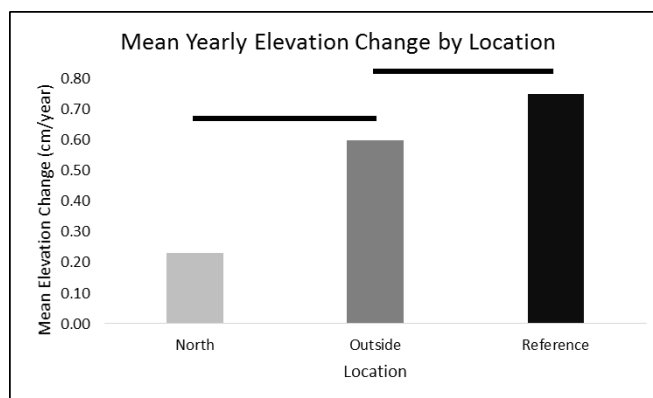


Figure 16. Fisher LSD contrast of mean yearly surface elevation change by location. The solid black bars indicate significant similarity between locations. The bars show that the north and reference locations do not have similar changes in sediment elevation.

2.3.7 Primary Productivity

The mean net primary productivity across all sites within the preserve was measured at 374g/m²/year (Table 3). The high marsh sites just outside of the restoration area had the greatest productivity of the sampled sites (mean = 629g/m²/year), with low marsh sites in the same location having the lowest measured NPP in the preserve (mean = 201g/m²/year), showing a difference of over 400g/m²/year between the marsh types (Figure 17, Table 3). The productivity between the high and low marshes at the other locations fell between that of the high and low marshes in the outside location, and only differed from 50-100g/m²/year between marsh types at each location (Figure 17, Table 3). The most productive low marsh sites were in the north location (427g/m²/year), having greater NPP than all but the most productive high marsh sites in the outside location, and due to dense the stands of *Schoenoplectus americanus* in the north that were not found in such abundance elsewhere (Figure 17, Table 4).

Examining the combined means of the high and low marshes by location shows that the outside location was the most productive (496g/m²/year), with north in the middle (375g/m²/year), and the reference had the lowest productivity (281g/m²/year), with the location shown to be a significant factor on productivity ($p < 0.05$) (Figure 17). The marsh type is also shown to have a significant effect on productivity, with the high marsh sites (420g/m²/year) having overall greater productivity than the low marsh sites (326g/m²/year) ($p < 0.05$) (Figure 18, Table 5). The interactive effect of location and marsh type was found to be significant, indicating that productivity is more similar within the replicate sites than

between the other locations or marsh types (e.g. the north low marsh sites are significantly different from all other sites) ($p < 0.05$) (Figure 17, Table 5).

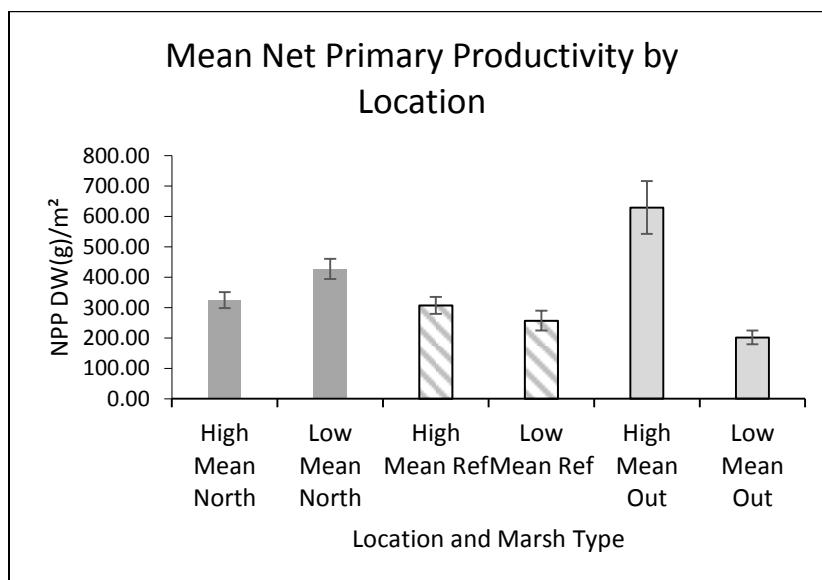


Figure 17. Mean net primary productivity by location (north, reference, and outside levee) and marsh type (high and low) with standard error displayed. In the reference and outside locations, the high marsh was more productive, whereas in the north sites the low marsh had higher productivity.

Site	Location	Marsh Type	DW(g)/m ²
1	North	High	293.74
2	North	High	354.85
3	North	Low	433.35
4	North	Low	421.25
7	Ref	High	280.28
8	Ref	High	334.03
9	Ref	Low	201.70
10	Ref	Low	311.64
11	Out	High	679.68
13	Out	Low	232.86
20	Out	High	578.73
		Total Average	374.74

Table 3. Peak biomass (NPP) at each site with the marsh type indicated. Total values for each site are the average of the three random clip plots.

Site	Sample	Species	Weight (g)	Plot Size (m ²)	Species DW(g)/m ²	Site	Sample	Species	Weight (g)	Plot Size (m ²)	Species DW(g)/m ²
1	1	SM	1.7	0.044075	38.57	8	2	G1	3.21	0.1332	24.10
1	1	BR	9.98	0.044075	226.43	8	2	AB	2.91	0.1332	21.85
1	1	G1	1.48	0.044075	33.58	8	2	AG	3.95	0.1332	29.65
1	1	SW	0.04	0.044075	0.91	8	2	JR	1.27	0.1332	9.53
1	2	SM	0.39	0.044075	8.85	8	3	SM	10.61	0.1332	79.65
1	2	BR	5.2	0.044075	117.98	8	3	BR	36.32	0.1332	272.67
1	2	G1	2.57	0.044075	58.31	8	3	G2	1.14	0.1332	8.56
1	2	SW	1.73	0.044075	39.25	9	1	AB	23.88	0.1332	179.28
1	3	SM	2.92	0.044075	66.25	9	2	G1	2.06	0.1332	15.47
1	3	BR	9.3	0.044075	211.00	9	2	AB	8.87	0.1332	66.59
1	3	G1	3.32	0.044075	75.33	9	2	AB	25.36	0.1332	190.39
1	3	SW	0.21	0.044075	4.76	9	3	AB	20.43	0.1332	153.38
2	1	BR	7.89	0.044075	179.01	10	1	AB	35.39	0.1332	265.69
2	1	G1	4.2	0.044075	95.29	10	2	AB	39.47	0.1332	296.32
2	1	SW	1.78	0.044075	40.39	10	3	BR	0.1	0.1332	0.75
2	2	BR/G1	12.78	0.044075	289.96	10	3	G1	0.7	0.1332	5.26
2	2	G1	4.79	0.044075	108.68	10	3	AB	48.87	0.1332	366.89
2	2	UNKWN	0.85	0.044075	19.29	11	1	SM	0.87	0.1332	6.53
2	3	AB	1.16	0.044075	26.32	11	1	G1	70.48	0.1332	529.13
2	3	G1	13.47	0.044075	305.62	11	1	AB	9.11	0.1332	68.39
3	1	AB	21.23	0.044075	481.68	11	1	JR	0.54	0.1332	4.05
3	2	AB	14.69	0.044075	333.30	11	2	SM	0.38	0.1332	2.85
3	3	AB	21.38	0.044075	485.08	11	2	G1	64.47	0.1332	484.01
4	1	AB	23.08	0.044075	523.65	11	2	SW	3.09	0.1332	23.20
4	2	AB	14.9	0.044075	338.06	11	2	AG	9.35	0.1332	70.20
4	3	AB	17.72	0.044075	402.04	11	3	SM	6.94	0.1332	52.10
7	1	SM	0.07	0.1332	0.53	11	3	G1	105.05	0.1332	788.66
7	1	BR	8.96	0.1332	67.27	11	3	AB	1.32	0.1332	9.91
7	1	G1	7.98	0.1332	59.91	13	1	AB	13.62	0.1332	102.25
7	1	AB	4.1	0.1332	30.78	13	1	HB	12.67	0.1332	95.12
7	1	TR	2.83	0.1332	21.25	13	2	SM	3.57	0.1332	26.80
7	2	SM	6.53	0.1332	49.02	13	2	AB	10.82	0.1332	81.23
7	2	BR	27.2	0.1332	204.20	13	2	HB	22.39	0.1332	168.09
7	2	G2	7.89	0.1332	59.23	13	3	AB	22.17	0.1332	166.44
7	2	AB	3.96	0.1332	29.73	13	3	HB	7.67	0.1332	57.58
7	2	TR	1.84	0.1332	13.81	13	3	UNKWN	0.14	0.1332	1.05
7	3	SM	0.46	0.1332	3.45	20	1	SM	1.77	0.1332	13.29
7	3	BR	28.34	0.1332	212.76	20	1	G1	95.32	0.1332	715.62
7	3	G2	11.84	0.1332	88.89	20	1	SW	2.02	0.1332	15.17
8	1	SM	2.76	0.1332	20.72	20	1	CR	1.26	0.1332	9.46
8	1	BR	28.69	0.1332	215.39	20	2	SM	3.78	0.1332	28.38
8	1	G1	6.03	0.1332	45.27	20	2	G1	91.5	0.1332	686.94
8	1	AB	1.55	0.1332	11.64	20	2	CR	3.12	0.1332	23.42
8	1	AG	0.84	0.1332	6.31	20	3	SM	3.51	0.1332	26.35
8	2	SM	15.06	0.1332	113.06	20	3	G1	20.66	0.1332	155.11
8	2	BR	19.14	0.1332	143.69	20	3	DA	8.32	0.1332	62.46

Table 4. This table shows the species contribution to NPP at each clip plot. Sites are based on the SET site numbers, with 3 samples per site. AB = *Schoenoplectus americanus*, BR = *Juncus balticus*, CR = *Juncus effusus*, DA = *Aster subspicatus*, G1 = *Distichlis spicata*, G2 = *Agrostis exarata*, HB = *Schoenoplectus acutus*, JR = *Juncus articulatus*, SM = *Schoenoplectus maritimus*, SW = *Potentilla anserina*, TR = *Juncus acuminatus*.

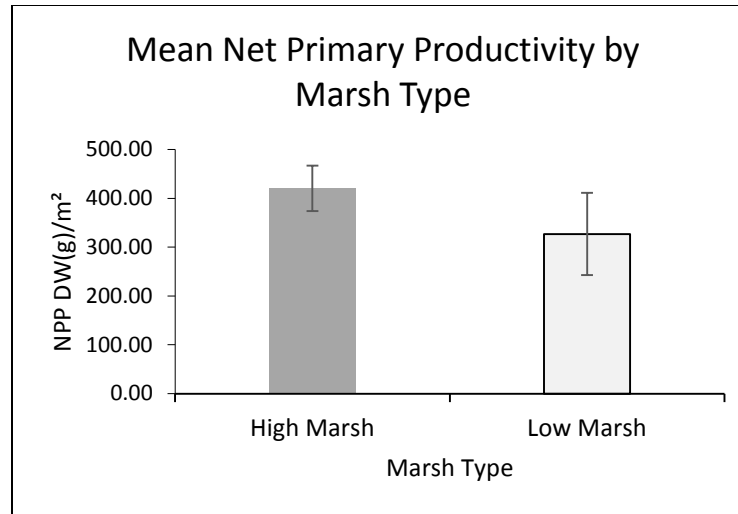


Figure 18. Mean net primary productivity by marsh type (high and low) with standard error displayed. This indicates that on average across the preserve, the high marsh sites are more productive than the low marsh sites.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Location	115526.359	2	57763.179	4.594	.019
Marsh type	101329.648	1	101329.648	8.060	.008
Location * Marsh type	303234.608	2	151617.304	12.059	.000
Error	339458.724	27	12572.545		
Corrected Total	931259.634	32			

Table 5. Two-factor ANOVA with location and marsh type effect on NPP, indicating a significant interaction between location and marsh type on the measured NPP.

2.3.8 Physical and biological variance in surface elevation change

The correlation variables, mean surface elevation change, mean accretion rate, mean shallow subsidence, elevation, and net primary productivity, all meet the assumption of normality (mean surface elevation change: Shapiro Wilk (W) = 0.905, $p = 0.249$; mean accretion rate: $W = 0.917$, $p = 0.336$; mean shallow subsidence: $W = 0.973$, $p = 0.918$; elevation: $W = 0.914$, $p = 0.310$; net primary productivity: $W = 0.926$, $p = 0.407$). An outlier was found in the data, with one clip plot at site 11 substantially higher than the other

samples in site 11 and those from other sites, and due to this I excluded that clip plot from the mean NPP for site 11 for a better model fit.

I found a significant negative relationship between the mean rate of elevation change and net primary productivity ($r^2 = 0.537$, $p = 0.01$, $n = 10$). The trend line indicates that as biomass increases there is a drop in the rate of elevation change, especially prevalent at the north sites, where sites with the lowest biomass gain about 6mm/year and higher productivity sites show a loss in the elevation of close to -2.5mm (Figure 19).

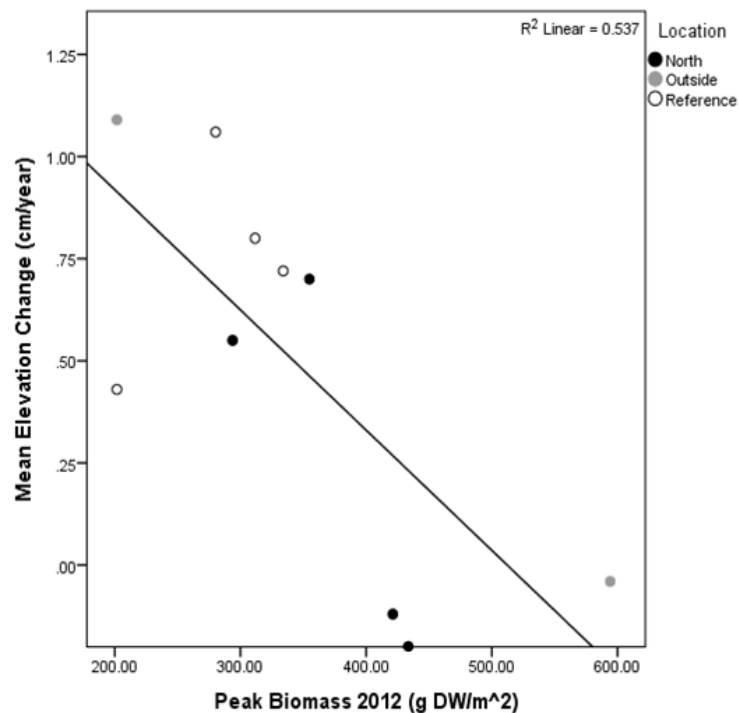


Figure 19. Significant ($p = 0.01$) relationship between the mean rate of elevation change per year and the net primary productivity (peak biomass in 2012).

I observed a significant negative correlation between the yearly mean shallow subsidence and net primary productivity ($r^2 = 0.440$, $p = 0.03$, $n = 10$). Indicating that as peak biomass increases, there is an increased effect of shallow subsidence in that area (Figure 20).

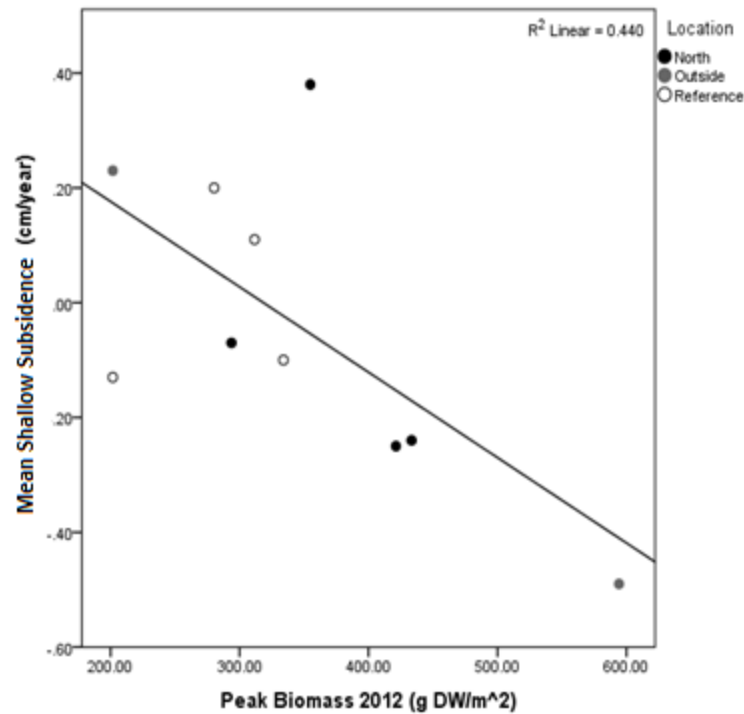


Figure 20. Significant ($p = 0.03$) relationship between the mean rate of change from shallow soil processes (subsidence or gain) and the net primary productivity (peak biomass in 2012).

I detected a generally negative, though non-significant, relationship between the mean rate of accretion and net primary productivity ($r^2 = 0.336$, $p = 0.07$, $n = 10$). This trend line may not be significant, but there is an observable pattern of decreased accretion as the peak biomass increases throughout the majority of the preserve (Figure 21).

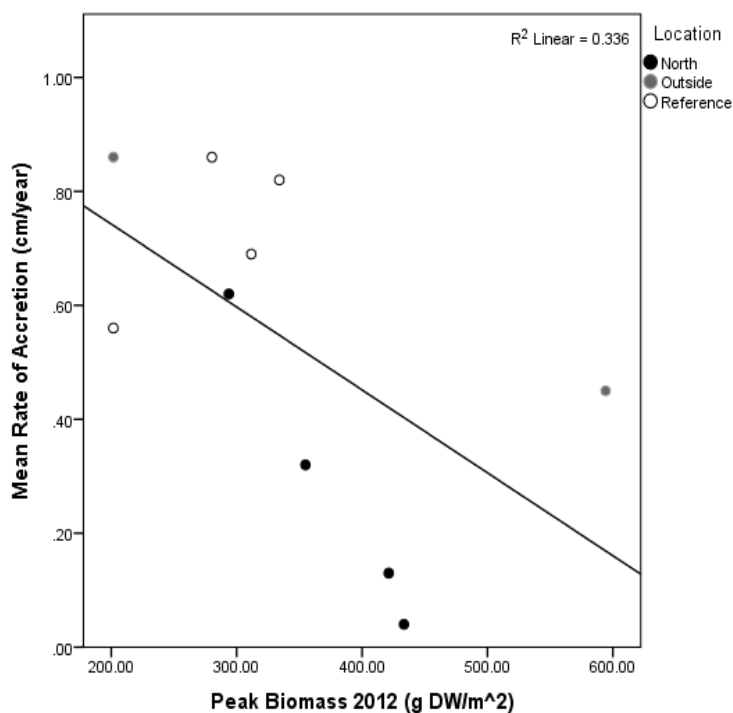


Figure 21. Non-significant ($p = 0.07$) relationship between the mean yearly rate of sediment accretion and net primary productivity (peak biomass in 2012).

I did not find a significant relationship between the surveyed elevations determined at the sediment surface for each SET site and the NPP sampled at those sites ($p = 0.7$). The surveyed elevation was not significantly correlated with any of the other measured variables either: mean yearly elevation change ($p = 0.3$), mean yearly accretion ($p = 0.3$), or mean yearly shallow subsidence ($p = 0.2$), so that no trends between elevation and the measured variables could be determined.

2.3.8.1 Removal of site 11

I removed SET 11 from the analysis to look for a more significant correlation with the other variables, this was justified by the behavior of that SET over the sampling years, with a large loss of elevation in 2012 and an equal gain in 2013, resulting in no substantial change mean surface elevations, beyond the standard error (Figure 22). Removal of SET 11 from the

analysis, yielded a better relationship between the mean yearly elevation change and the elevation, the trend is of increasing sediment surface elevation gain with increased elevation ($p = 0.1$, $r^2 = 0.332$, $n = 9$) (Figure 23). A clearer positive trend in the rate of shallow subsidence with elevation was found, as elevation increases there is a positive gain in elevation from shallow subsidence, though still not below the threshold of significance ($p = 0.07$, $r^2 = 0.332$, $n = 9$) (Figure 24). The trend between elevation and mean yearly sediment accretion is also improved by the removal of site 11, showing a potential positive trend of more accretion with higher elevation ($p = 0.279$, $r^2 = 0.165$, $n=9$) (Figure 25). Slightly improved, though still non-significant, was the regression between the elevation and peak biomass in 2012 (NPP), no trend can be determined between all locations ($p = 0.5$, $r^2 = 0.059$, $n = 9$) (Figure 26). These improvements in the relationship of variables with elevation, a proven indicator of trends in an estuary, indicates that site 11 may have had an effect present that was not at the other sites, such as a localized disturbance or the greater presence of distributary channels in the outside area.

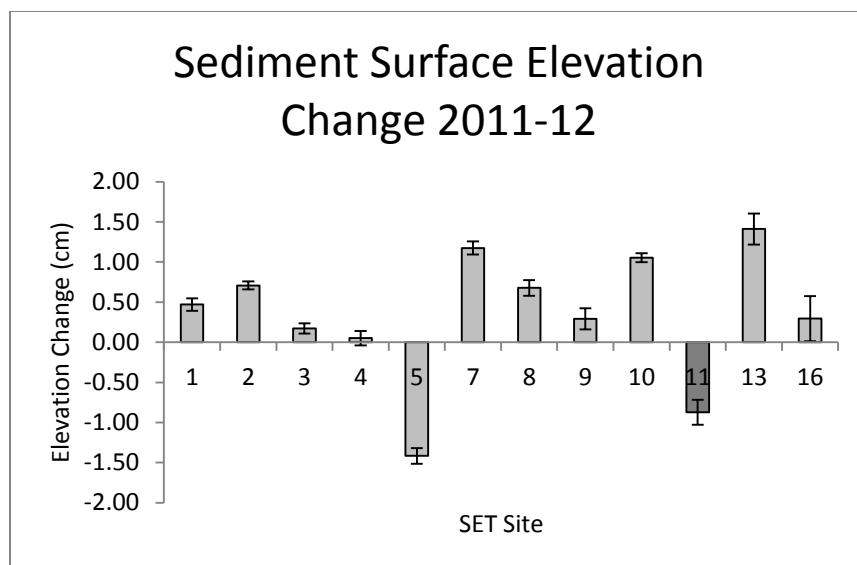


Figure 22. Surface elevation change as measured in 2012. Showing a loss of surface elevation at SET site 11 from 2011-12 (-0.87cm). Note: there was a sampling of error of $\pm 0.3\text{cm}$ during this year and all data was excluded from analysis.

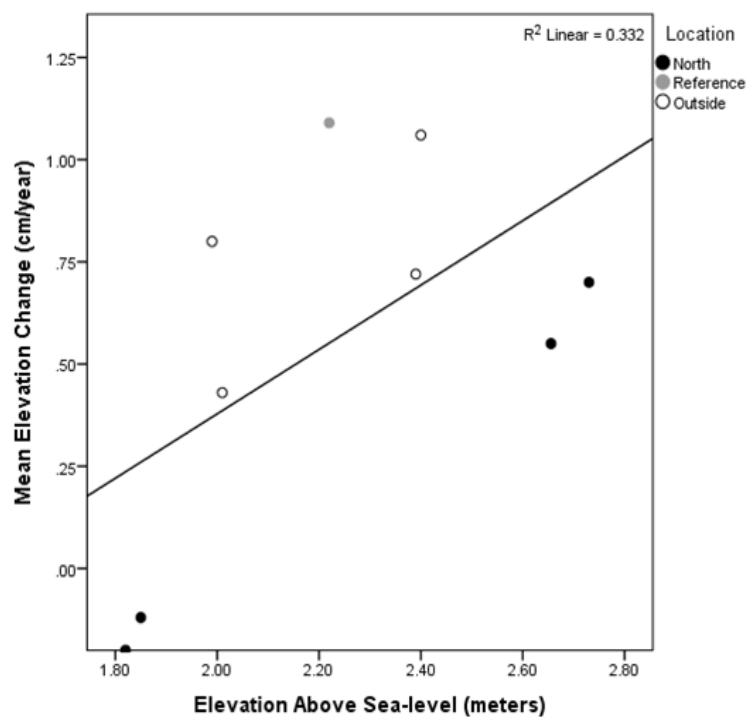


Figure 23. Non-significant ($p = 0.1$) relationship between the elevation and the mean elevation change. Site 11 has been removed from this analysis.

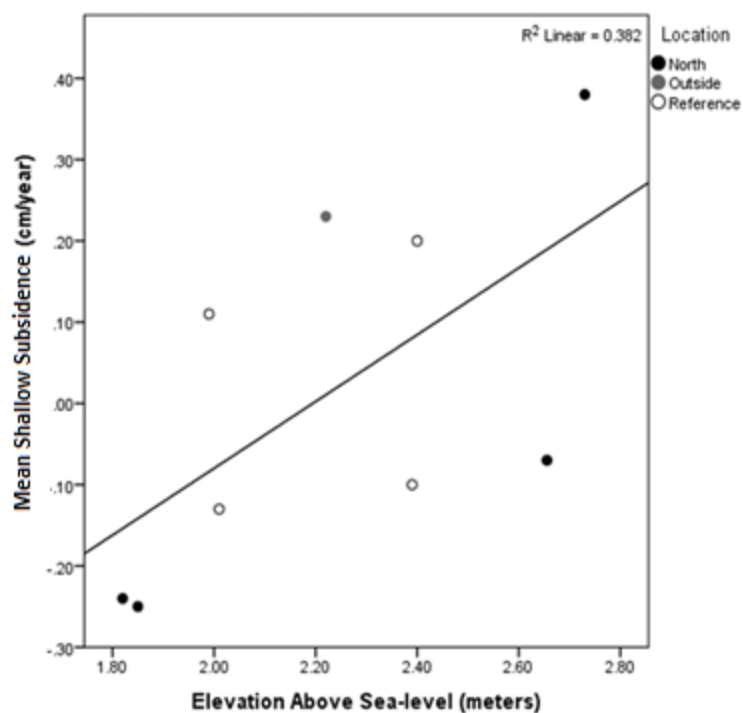


Figure 24. Non-significant ($p = 0.07$) relationship between the elevation and the mean shallow subsidence. Site 11 has been removed from this analysis.

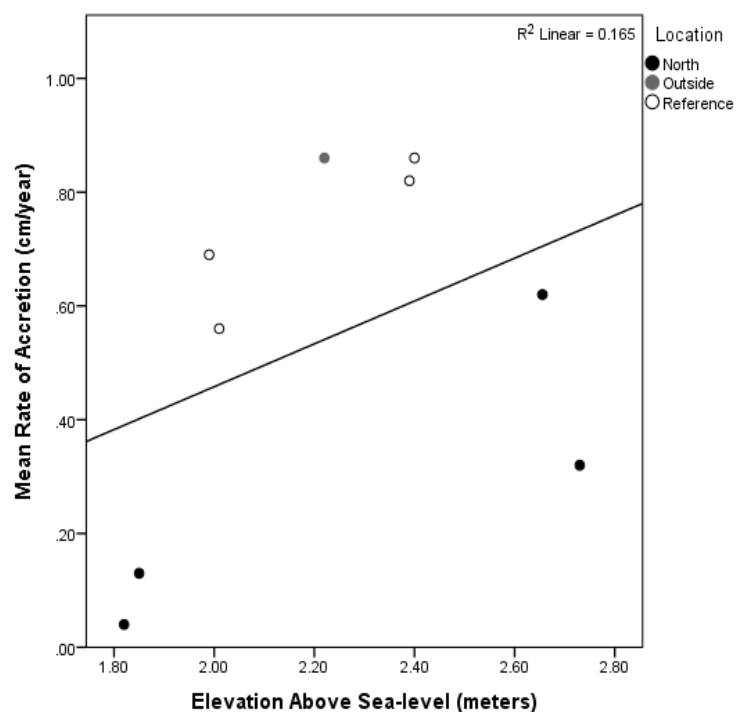


Figure 25. Non-significant ($p = 0.27$) relationship between the elevation and the mean rate of accretion. Site 11 has been removed from this analysis.

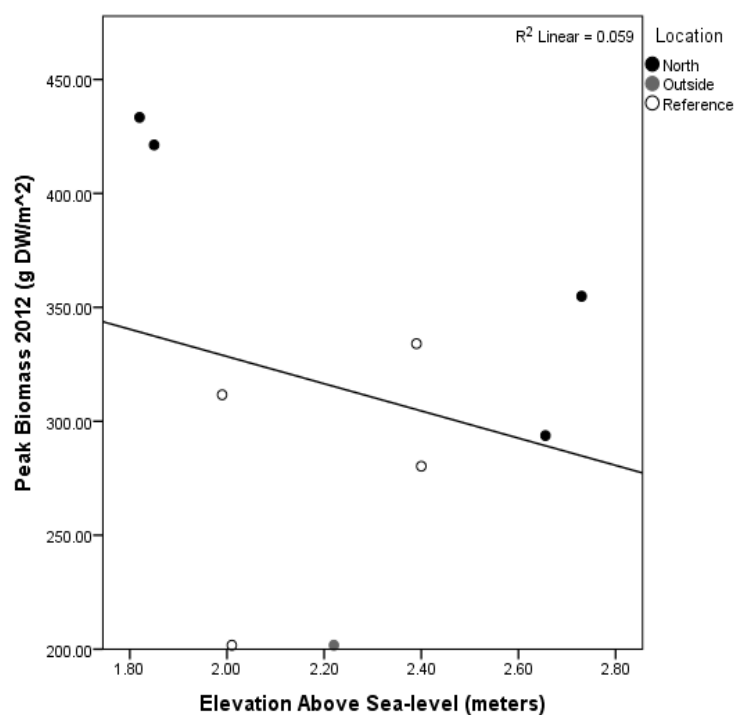


Figure 26. Non-significant ($p = 0.5$) relationship between the elevation and the peak biomass in 2012 (NPP). Site 11 has been removed from this analysis.

2.4 Discussion

2.4.1 Sediment dynamics

Surface elevation tables indicate that during the scope of this project, the rates of surface elevation gain at most of the SETs within PSB were higher than the current rate of sea level rise in the area, as measured from the nearest tidal gauge station in Port Townsend (1.98mm/year), also higher than the rate calculated from the global mean (3.4-4.8mm/year) (Figures 14 and 15) (Church and White 2006, 2011, NOAA). The high rates of accretion and low to negative rates of shallow subsidence indicates that most of the surface elevation gain within the preserve is through the deposition of sediment, likely from the Stillaguamish River, with nearby systems that lack those riverine inputs showing losses in elevation (Figure 13) (Kuhlman 2011). There were some unaccounted for gains in elevation

at 3 sites (2, 7, and 10), which may have been due to in situ biomass deposition, which was not measured (Figure 11). The surplus in elevation gain found at most of the sites (8 of 11), after accounting for RSLR and GMSLR, indicates that the estuary at PSB is currently receiving adequate material from the Stillaguamish River, surpassing that required to keep equilibrium, perhaps indicating expansion seaward of the vegetated marsh (Figures 14 and 15). Morris et al. (2002) has demonstrated that systems may see increased rates of surface elevation gain with increasing RSLR, linking productivity with accretion of sediment and biomass buildup as the estuary continually adjusts to maintain equilibrium, potentially allowing for PSB to continue to be sustainable by increasing the rate of sediment surface gain in the face of continually increasing sea level rise, even above current rates of elevation gain.

The only losses in surface elevation were found at sites 3, 4, and 11. Two of the sites (sites 3 and 4) are located at South Slough in the north area of the preserve, the most disconnected locations from the main flow of the Stillaguamish River. The South Slough channel appears to have insufficient flow for adequate sediment transport and is predicted to be predominately tidally influenced. Those sites are showing signs of erosional processes, with sediment loss found in the marker horizons and terracing of shore banks between the high and low marsh elevations. Similar processes are taking place in the Padilla Bay estuary, just north of PSB, which is a solely tidally influenced estuarine system, that is also losing sediment to erosional processes, having been disconnected from the Skagit River through human modification similarly to the South Slough channel (Kuhlman 2011). The third site losing elevation (site 11) is located outside the levees, this SET

indicated an elevation loss during the scope of sampling, but marker horizons showed accretion over those same two years, yielding shallow surface processes (unaccounted for change) much higher than those found at the other sites (Figure 13). This could indicate an unknown factor, such as a localized disturbance, which may be influencing the surface elevation at SET site 11 during this project. I predict that with more time the SET will indicate steady gains in surface elevation that are close to the accretion rates found in the adjacent markers.

2.4.2 *Net primary productivity*

High marsh sites were found to be more productive in the outside and reference locations, while the low marsh sites had higher productivity at the north locations, indicating that there may be dissimilarities in the factors that drive productivity across the preserve. The highest productivity was seen in the high marsh sites just outside of the restoration farmland and along one of the largest distributary channels cutting through the preserve from the main stem, this position provides more nutrients, less frequent tidal inundation and regular flushing of fresh water from the river. An opposite trend in productivity was observed at the north sites, where a loss in flow from the Stillaguamish River through the South Slough is occurring, so that high marsh sites are no longer located along a major fresh water channel, therefor most likely not receiving the same nutrient loads or regular flushing as the southern sites. The low marsh sites in the north would still receive regular nutrient input and flushing from the daily tides, leading to higher productivity there compared to the high marsh sites. Further, there was more woody debris, such as large logs, within the high marsh area to the north, this debris may be

mobile during higher tides and could lead to disturbance of the high marsh vegetation, and therefore potentially decreasing productivity.

The max productivity of $679\text{g/m}^2/\text{year}$ at Port Susan Bay was less than what was found in previous studies conducted in nearby systems, with findings in the Skagit River delta at $1,742\text{g/m}^2/\text{year}$ and $1,629\text{g/m}^2/\text{year}$ in the Nooksack River (Disraeli and Fonda 1979, Ewing 1986). A possible cause for the lower productivity could have been the limited scope of the sampling, only sampling in areas near the SETs and potentially missing more productive areas. Even though PSB proved to be less productive than nearby systems, the estuary shows a rate of surface elevation gain that is above the current rate of sea level rise at most sites, indicating that the productivity of this system's vegetation is capable of maintaining equilibrium (Morris et al. 2002).

2.4.3 Physical and biological variance in surface elevation dynamics

Based on previous studies, the expected results should have been increased accretion and elevation gain as more sediment entrapping vegetation was present (Morris et al. 2002). I found an opposite trend at PSB, indicating that productivity alone may not be a good indicator for surface elevation change, as increased vegetative presence should lead to more sediment accretion and elevation gain (Figures 19, 20, and 21). Experimentation has shown that stem density is more important to the retention and accretion of sediment in a salt marsh, with plots having greater stem densities also having more sediment accreted over the same period of time (Gleason et al. 1979). Areas having higher productivity in Port Susan Bay may have had more above ground biomass, but fewer stems at the surface compared to lower productive sites. It was also observed that during the

winter months, high marsh vegetation was more persistent than the low marsh, which would lead to greater retention of sediment in the high marsh over those months. Further, present work within the Padilla Bay Reserve is demonstrating that stem density may be better correlated to sediment deposition, with higher stem density areas having more sediment accretion and therefore elevation gain.

The surveyed elevation of the SETs does not appear to have a significant influence on the pattern of surface processes seen over the scope of the project or the NPP sampled in 2012 (Figure 22). Though the high marsh was overall more productive, I expected to see a clear relationship of increasing primary productivity with rising elevation in the estuary. As stated previously, elevation is a determinant of many processes, affecting flood frequency, and therefore sediment transport potential and soil salinities, so that elevation should have been significantly correlated with most or all sampled variables.

The removal of a potentially outlying site (site 11), yielded some interesting results, improving the detectable influence of elevation, with a positive trend between surface elevation change and the elevation above sea level, though non-significant (Figure 23). The other surface dynamics of shallow subsidence and sediment accretion show an improved positive trend with elevation (Figures 25 and 26). With further data collection, these relationships could become more significant and support the hypothesis of elevation controlling the surface processes, not productivity as was seen.

3 VEGETATION COMMUNITY STRUCTURE

3.1 Objectives

The objectives of my vegetation sampling and analysis were to determine how elevation shapes community structures within the preserve and how those structures differ between the elevations. I sought to determine if there were significant differences in species structure between the high marsh and low marsh sites, and if the restoration area is similar to anywhere else in the preserve. Based on ground observations, I hypothesized that the high and low marsh sites were differently structured, and that the restoration area more closely resembles the low marsh sites with a subsided soil elevation and regular water inundation.

Hypotheses:

1. Vegetation community structures differ between the high and low marsh sites. As elevation relates to flood frequency and salinity, less tolerant species are less abundant in lower elevations where those stressors are more frequent.
2. The restoration area will have a unique structure from the rest of the estuary, being at an elevation lower than the high marsh outside the levees and historically isolated from the tidal system.

3.2 Methods

3.2.1 *Transects*

Vegetation transects were run at one of the replicate SETs in each location and marsh type, so that one site was sampled in each replicate SET pair. Four 50 meter transects were sampled at each of these locations, going from pin to water (westward) and

pin to shore (eastward), and two parallel to the shore from the pin (northward and southward). Data collection consisted of placing a 50 meter tape measure along transects and walking the length while recording point intercept data of dominant vegetation species (tallest) and the height of the dominant vegetation at 1 meter intervals. These sampling procedures closely follow standard operating procedures from the US Geological Survey (USGS 2011).

3.2.2 Quadrats

Quadrats of one square meter were sampled at the 0, 19.5, and 39 meter points along the 50 meter transect in all four directions from the SET, yielding a sample size of 12 plots per SET and 24 plots per location (north, outside, reference). James-Pirri et al. (2007) suggest a minimum sample size of 20 plots per location to detect vegetation community change in a salt marsh. All living plant species present within the quadrat and the percent ground cover for each species were recorded.

3.2.3 Data analysis

3.2.3.1 PRIMER

The program PRIMER 6 was utilized for the analysis of all vegetation community data. The PRIMER statistical package uses a Bray-Curtis similarity index to assess the similarity (or dissimilarity) of species composition between two given communities, as a function of the species present and their relative abundances in both communities. Full details of the program can be found in the user manual/tutorial, see (Clarke and Gorley 2001 & 2006).

3.2.3.2 Removal of bare soil plots

Within the restoration sites, many points and quadrats along the sampled transects were recorded as having only bare soil. This was likely due to the permanent inundation of water seen at the site before draining for the levee removal work, which greatly influenced the vegetation community structure within the restoration sites through exclusion of vegetation in the areas with the greatest depths. Leading to a separation from the surrounding estuary based on the non-presence of species in some area and influenced by a unique factor to the farm sites, no sites outside the farmland had large areas of bare soil. Transects and quadrats found to be containing 100% cover of bare soil were removed from the analysis.

3.2.3.3 Transformation of data

To adjust for the presence of dominant species across many of the sites within the estuary, specifically the species *Schoenoplectus americanus*, *Schoenoplectus maritimus*, and *Schoenoplectus acutus*, a log transformation of the point-intercept data was utilized to lessen the influence that a dominant species present across many sites would have on the analysis, allowing for less abundant species that may be found in only a few sites to have a greater weight on community structure and showing differences between sample sites that may not be observable with the full presence of those three dominant species. Quadrat data were not transformed, transformation made little difference in the site grouping as sampling procedures gave a more complete picture of species presence, compared to the point-intercept sampling of only the most dominant species present at each sampling point.

3.2.3.4 Nonmetric multidimensional scaling

Nonmetric multidimensional scaling (NMDS) is a nonmetric method of ordination utilizing compositional similarity to create a two-dimensional graphical output of community patterns (Clarke 1993). A Bray-Curtis similarity matrix is created from the species community data, the matrix is then ranked and the NMDS is created based upon those ranks, mapping the sample sites by placing the most similar sites nearest to each other and more dissimilar sites further apart.

The accuracy of an NMDS output can be determined based upon a stress coefficient associated with each NMDS, stress values are determined by comparing the two-dimensional results of the NMDS to the higher dimensional relationship in the data, with a stress value of 0.05-0.1 being considered a good fit, with a low probability of misrepresentative patterns in the data (Clarke and Warrick 2001). A stress of 0.1-0.2 is still considered a good representation for ecological abundance data, with the threshold of 0.3 being the cutoff for satisfactory interpretation of the data from the model (Quinn and Keough 2002). Repetition of the process is imperative in assuring that low stress NMDS results are not caused by random chance, to avoid the statistical artifacts of random chance, 25 iterations were run and stress values compared for consistency (Clarke 1993).

The graphical output of an NMDS has no axis, enabling the data to be flipped and rotated in order to show the best possible view of the groups. Emphasis should be made on the distances between samples or points, not their orientation. The points in the ordination can be labeled with any of the sampled or known factors present at the sites to aid in determining the trends of the clustering.

3.2.3.5 Analysis of similarity

Analysis of similarity (ANOSIM) is a multivariate non-parametric statistical method using permutation/randomization tests that make few assumptions about the data and is often paired the NMDS tests for the significance of observed clustering (Clarke and Warwick 2001). ANOSIM utilizes the same rank based similarity matrix used to generate the NMDS output, determining the similarity within a group and comparing that to the similarity between the other site location groups. The process is analogous to that of an ANOVA.

The test statistic R is used to determine the level of separation between the groups of interest, $R \geq 0.75$ = well separated, $0.75 > R \geq 0.5$ = overlapping but different, $0.5 > R \geq 0.25$ = overlapping but somewhat different, $R < 0.25$ = insufficiently different, with the global R statistic showing the total amount of separation between the groups, indicating the significance of the entire observed pattern (Clarke and Warwick 2001). The significance levels of the ANOSIM results are determined through randomization tests and the occurrence of the observed pattern within a randomized distribution, yielding a percent significance level of the sample statistic sites (Clarke and Warwick 2001). It should be noted that more emphasis should be placed on the R statistics than the level of significance (p-value) in this analysis, as the R value is the determinant of how separated the groups are. A one-way design using the factors marsh type and location were utilized in both the point-intercept and quadrat data, shown to be potential driver of clustering within both NMDS outputs.

3.2.3.6 Similarity percentages

The similarity percentages (SIMPER) process determines the contribution of a species to the similarity or difference between tested sample sites and locations. The SIMPER procedure uses the Bray-Curtis similarity matrix and is used in conjunction with the NMDS to determine an average similarity among factor groups and dissimilarity between groups and what major species are driving the observed pattern. The dissimilarity or similarity is based on a 0-100 scale of how different or similar the sites of interest are. The species can then be ranked, based on their overall importance towards the comparison, with the most important species having a higher percent contribution (Clarke and Warwick 2001). The presence of a species across the groups and at similar abundances would lead to a high contribution to the similarity of the sites from that species, whereas groups or sites with unique species in substantial quantities would yield a high weight toward dissimilarity. A one-way factor design using marsh type was utilized for the point-intercept and quadrat data, marsh type being the only factor indicating significant influence on the site group clustering.

3.3 Results

3.3.1 Nonmetric multidimensional scaling

3.3.1.1 Transect

Nonmetric multidimensional scaling (NMDS) of the dominant vegetation from the point intercept sampling indicates a clustering of the sites in the ordination and is considered a good fit to the data (stress = 0.09). When marsh type is used as the indicating factor, restoration sites are grouped with the low marsh sites, with high marsh sites

grouped apart from the low and restoration sites (Figure 27). Site 13 is the only site that does not fit into the observed pattern of marsh type. Designated as a low marsh site located within the outside levee area, the site lies separate from the other low marsh sites, placed between the low and high marsh sites (Figure 27). There is an apparent grouping of the sites by their location within the preserve with the restoration and outside sites close together, although the location does not appear to represent the reference and north sites well, as they do not follow the pattern seen in the reference and outside sites. Species compositions at the reference and north sites are more likely driven by a different factor than location (Figure 28).

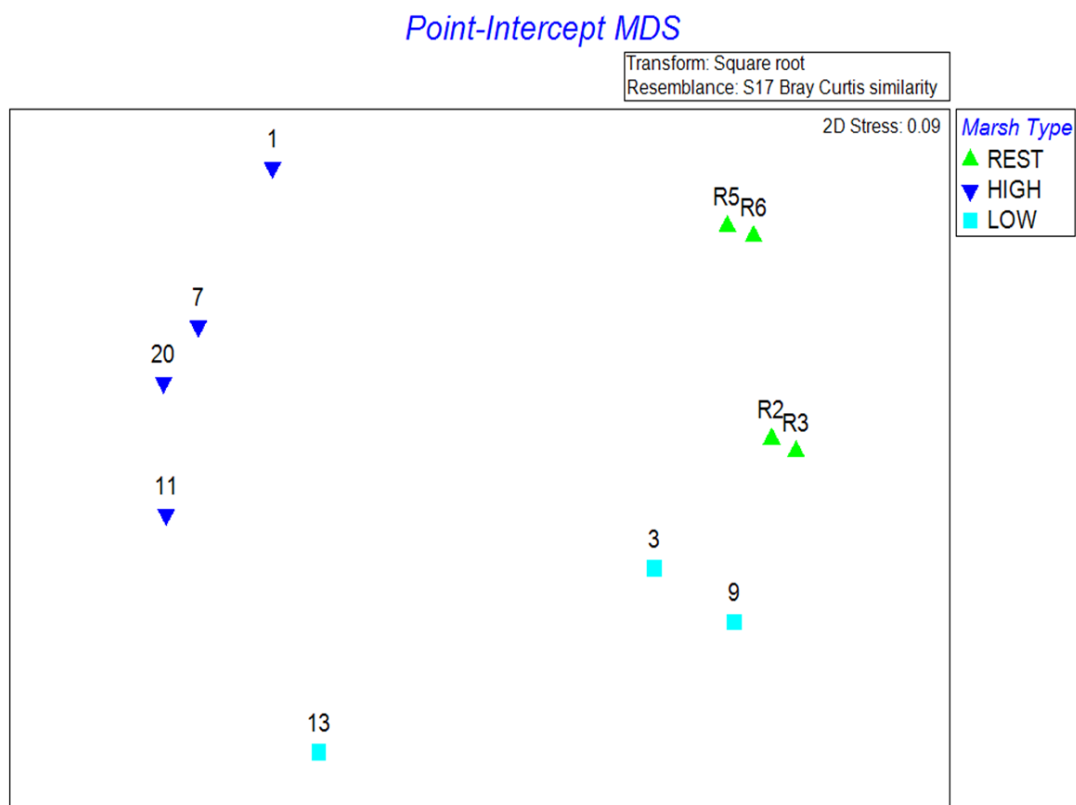


Figure 27. NMDS output for vegetation point intercept data by marsh type. Placing the restoration and low marsh sites together, with high marsh sites grouped apart from them. Site 13 is located at a mid-point between the two groupings.

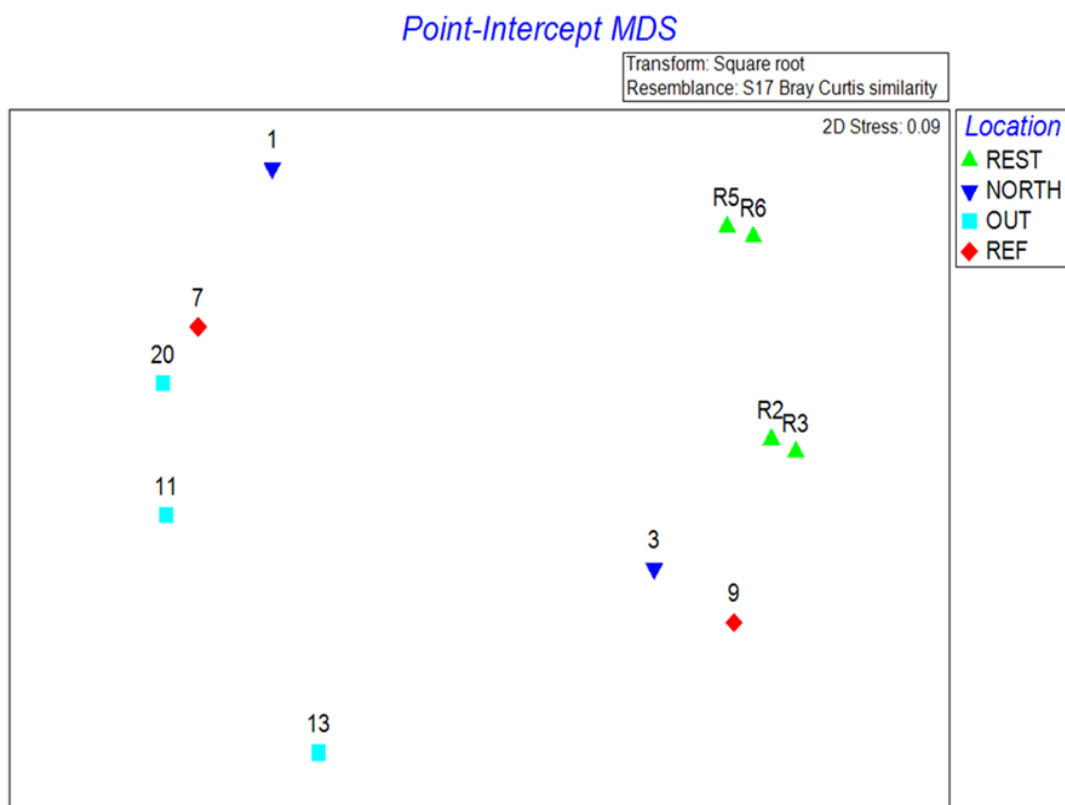


Figure 28. NMDS output of vegetation point intercept data by location within the preserve. Placing the restoration with the low marsh sites from the north and reference locations, with high marsh sites from all locations grouped separately. Site 13, a low marsh outside site is located at a mid-point between the two groupings.

3.3.1.2 Quadrat

NMDS ordination of the vegetation quadrats indicates a clustering of the sites with a model stress that is considered within the good representation range for the data (stress = 0.14). Displaying marsh type as the indicating factor shows an interspersing of the restoration quadrats with the low marsh, along with a clear separation of the high marsh quadrats from the other types (Figure 29). There appears to be some grouping of the restoration quadrats by their location, no other apparent location groups can be seen though, with interspersing of points throughout the ordination from the other locations

(Figure 30). When the graphs are compared, the interspersing of the sites by location is due mostly to the marsh type (Figures 29 and 30).

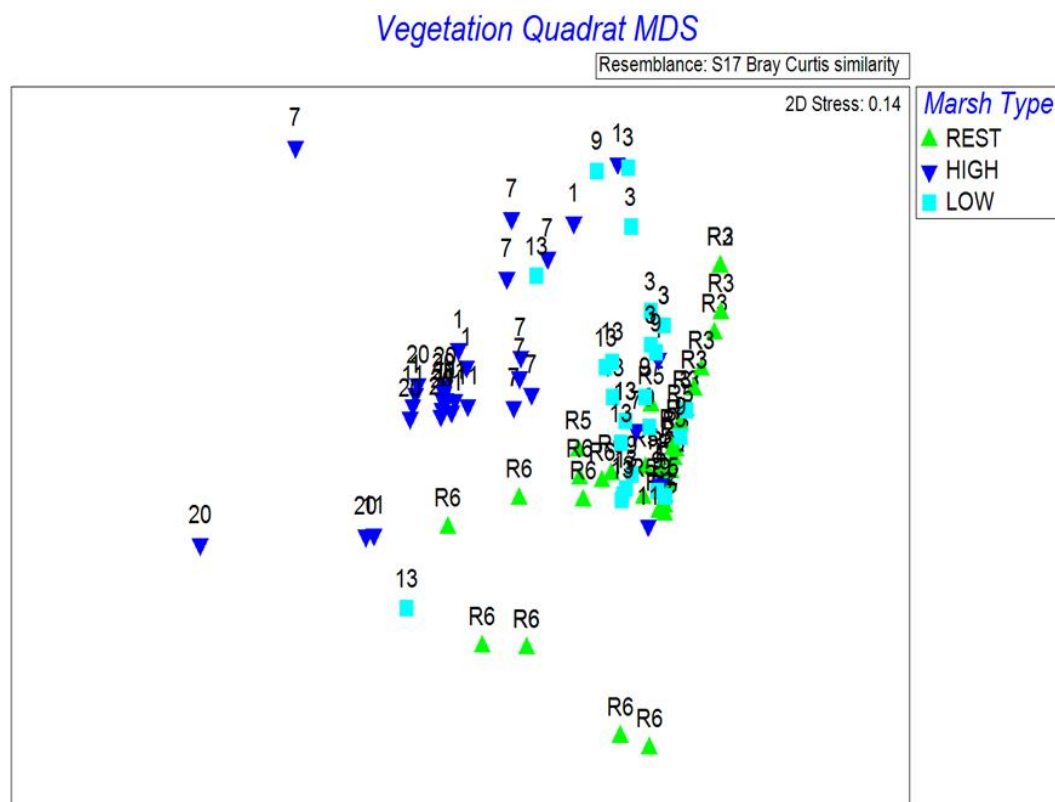


Figure 29. NMDS output for vegetation quadrat data by marsh type. With little overlap, the low marsh and restoration plots are grouped together, with high marsh plots separately grouped.

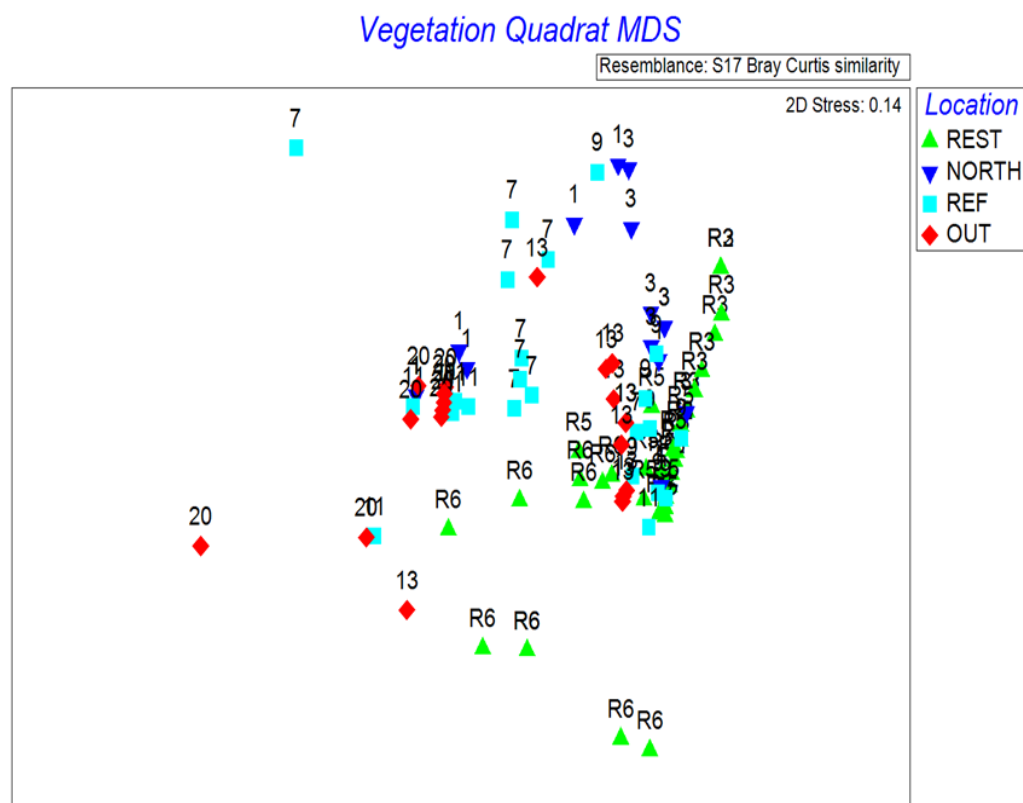


Figure 30. NMDS output of vegetation quadrat data by location within the preserve. The restoration plots are grouped together, with few sites dispersed out. The other locations are intermixed by their marsh types.

3.3.2 Analysis of similarity

3.3.2.1 Transect

Single factor one-way analysis of the ranked data using the assigned marsh type as the indicator shows that the observed pattern is well separated by groups and significant (global $r=0.81$, $p=0.03$). The restoration and high marsh types show a significant difference in species composition, being considered well separated ($r=1$, $p=0.029$). The high and low marsh sites are also shown to be well separated in community structure between the two marsh types ($r=0.796$, $p=0.029$). Sites designated as the restoration and low marsh are the least dissimilar of the three marsh types, having an overlap in vegetation, but still considered different in the analysis ($r=0.537$, $p=0.029$).

A single factor one-way analysis with the assigned location of the sites within the preserve indicates the model has some overlapping in location designations, but the whole of the groups are considered different (global $r=0.665$, $p=0.03$). The results show that the restoration sites are the most dissimilar from the outside sites and are the only statistically significant comparison using the location of the sites within the preserve ($r=1$, $p=0.029$). The remaining similarity analysis using the location exceeds the threshold of statistical significance in each comparison ($p>0.05$). The ANOSIM results indicate that location is not a significant driver of the overall observed community pattern, with only one significant pairwise comparison.

3.3.2.2 *Quadrat*

Single factor one-way analysis using the marsh type as the indicating factor is significant and demonstrates the greatest difference between groups across the model (global $r=0.404$, $p=0.01$). The restoration and high marsh sites are the most dissimilar of the marsh types, showing some overlap of vegetation, but still considered different ($r=0.536$, $p=0.01$). The high and low marsh sites overlap, considered somewhat different ($r=0.495$, $p=0.01$). Restoration and low marsh sites are shown to be the least dissimilar of the marsh types in the analysis, considered insufficiently different ($r=0.124$, $p=0.01$).

Single factor one-way analysis using the location within the preserve as the indicating factor is significant, but shows little to no difference in species composition between the locations ($p<0.05$, $r<0.15-0.37$). This indicates that the location within the preserve is not a determinant of species composition, with locations being insufficiently dissimilar between each other.

3.3.3 Similarity percentages

3.3.3.1 Transect

One-way SIMPER analysis of marsh type, the only factor designated as significant, indicates that the group with the most similarity among the sites is the restoration group (similarity = 64.21), with the high marsh group showing a moderate level of similarity among the sites (similarity = 54.67), and the low marsh group showing the least similarity within the grouping (similarity = 51.12). Comparison between the marsh types show that the greatest dissimilarity between groupings is seen between the restoration and high marsh types and driven mostly by *Distichlis spicata* (13.35%), *Schoenoplectus americanus* (12.54%), and *Typha augustifolia* (9.14%) (average dissimilarity = 71.91). The high and low marsh sites being the next most dissimilar and driven mostly by *Distichlis spicata* (16.55%), *Schoenoplectus acutus* (17.26%), and *Schoenoplectus americanus* (10.92%) (average dissimilarity = 63.64). The two groups indicating the least dissimilarity are the restoration and low marsh types and driven mostly by *Schoenoplectus maritimus* (26.98%), *Schoenoplectus acutus* (17.26%), *Schoenoplectus americanus* (14.81%) (average dissimilarity = 53.35).

The restoration area is most closely associated with *Schoenoplectus americanus* (avg. abundance = 10.26). The low marsh is most closely associated with *Schoenoplectus americanus* (avg. abundance = 9.47), and *Schoenoplectus maritimus* (avg. abundance = 5.21). The high marsh is most closely associated with *Distichlis spicata* (avg. abundance = 7.05), and *Schoenoplectus americanus* (avg. abundance = 5.34).

3.3.3.2 Quadrat

One-way SIMPER analysis using the marsh type indicates comparable within group similarities at all of the sites across the preserve (average similarities, rest = 38.12, low = 38.47, high = 36.92). The between group dissimilarity comparisons indicate that the greatest difference in marsh types are between the restoration and high marsh type sites and driven mostly by *Distichlis spicata* (51.10%), *Schoenoplectus americanus* (20.5%) and *Juncus effuses* (6.22%) (average dissimilarity = 91.54). The high and low marsh type sites are also indicated as being very dissimilar to each other and driven mostly by *Distichlis spicata* (47.93%), *Schoenoplectus americanus* (20.29%), and *Juncus effusus* (9.59%) (average dissimilarity = 88.79). The pair of sites with the least dissimilarity between them, are the restoration and low marsh types and driven mostly by *Schoenoplectus americanus* (45.71%), *Schoenoplectus maritimus* (19.16%), and *Juncus effusus* (16.63%) (average dissimilarity = 67.98).

The restoration area is most closely associated with *Schoenoplectus americanus* (avg. abundance = 15.22). The low marsh is most closely associated with *Schoenoplectus americanus* (avg. abundance = 16.91), *Schoenoplectus maritimus* (avg. abundance = 5.0), and *Juncus effusus* (avg. abundance = 6.15). The high marsh is most closely associated with *Distichlis spicata* (avg. abundance = 48.81), and *Juncus effusus* (avg. abundance = 3.9).

3.3.4 Combined NMDS and SIMPER

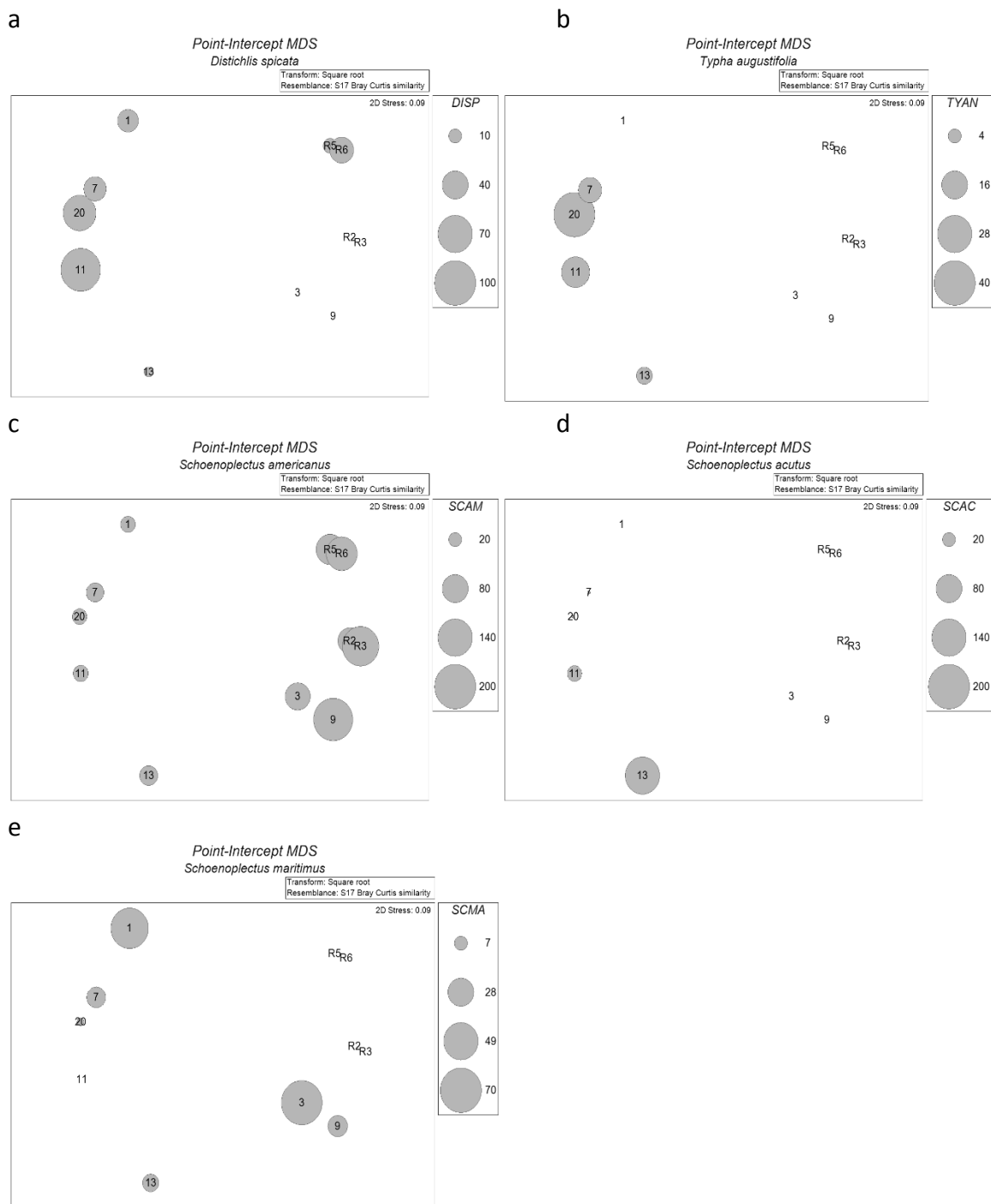
3.3.4.1 Transect

SIMPER analysis of the point-intercept vegetation transect data indicated that *Schoenoplectus americanus*, *Distichlis spicata*, *Schoenoplectus acutus*, *Schoenoplectus*

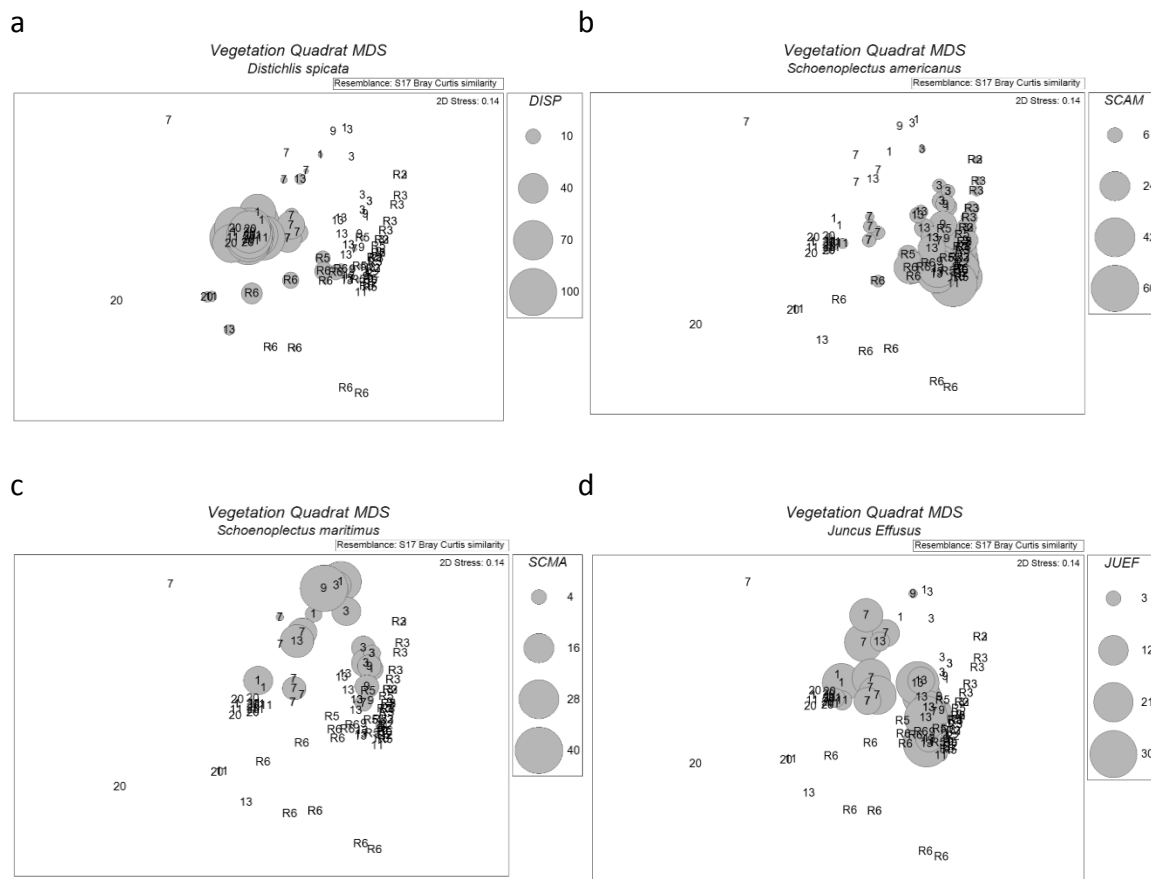
maritimus, and *Typha agustifolia* are the most significant drivers of the pattern, accounting for most of the site positioning within the NMDS output and demonstrating a differentiation of sites based on the assigned marsh type. The high marsh sites are defined by the presence of *Distichlis spicata* and *Typha agustifolia*, with little *Schoenoplectus americanus* or *Schoenoplectus acutus*. Excluding site 13, the low marsh sites contain only two of the indicating species, *Schoenoplectus americanus* and *Schoenoplectus maritimus*. Restoration marsh sites are characterized by a higher presence of *Schoenoplectus americanus*, without the presence of *Schoenoplectus maritimus*, *Schoenoplectus acutus* or *Typha agustifolia*. A higher presence of *Schoenoplectus acutus* at site 13 with the low presence at the high marsh and lack of the species within the restoration and other low marsh sites explains the outlying position of site 13 within the ordination (Figures 31a-e).

3.3.4.2 Quadrat

The SIMPER analysis of the quadrat data indicates that *Schoenoplectus americanus*, *Distichlis spicata*, *Schoenoplectus acutus*, *Schoenoplectus maritimus*, and *Juncus effusus* are the most significant drivers of the observed pattern, accounting for most of the site positioning within the NMDS ordination. The high marsh sites are defined by the high abundance of *Distichlis spicata*, and little presence of *Schoenoplectus americanus*. Low marsh sites are defined by the presence of *Schoenoplectus maritimus*, *Schoenoplectus americanus* and *Juncus effusus*, with little presence of *Distichlis spicata*. Restoration marsh sites are predominantly made up of a *Schoenoplectus americanus* monoculture, with little to no presence of the other indicator species (Figures 32a-d).



Figures 31a-e. Combined NMDS and SIMPER output of point vegetation data, indicating top species that are driving the site placement within the ordination. Circles size represents species abundance.



Figures 32a-d. Combined NMDS and SIMPER output of vegetation quadrat data, indicating top species that are driving the site placement within the ordination. Circles size represents species abundance, bigger circles = more abundant.

3.4 Discussion

Cui et al. (2011) have demonstrated that topographic gradients influence many abiotic factors driving vegetation zonation, such as sources of nutrients and freshwater, along with plant stressors including flood frequency and salinity. Vegetation transects conducted at PSB have indicated that community structures are significantly differentiated between the high and low marsh sites, demonstrating that there is sufficient change in elevation gradient between the marsh types to significantly alter community structure. The only exception to the overall trend of differentiated low and high marsh communities was at site 13, though this further supports the separation of vegetation communities based on

elevation gradients. Elevation survey data place the low marsh sites in the outside location at an elevation between the other sampled low and high marsh sites, and having a community structure also placed in between the other high and low marsh sites (Table 7).

The placement of the restoration sites close to the low marsh sites within both transect and quadrat ordinations indicates that they have similar factors driving their community structures, likely from regular flooding and salt water intrusion within the farmland. Aerial LIDAR imaging shows that the restoration and low marsh areas are very similar in elevation, indicating that elevation may be the main driver of the sampled community structure, even in areas that are physically separated. Furthermore, as tidal processes are reestablished, the similarity in community structure between the low marsh and restoration area indicates that the overall vegetation structure may not change much inside of the restoration area with returned tidal flow at the present elevation (Figures 2, 3, and 4).

SET Site	Marsh Type	Location	Elev. (meters)
1	High	North	2.66
2	High	North	2.73
3	Low	North	1.82
4	Low	North	1.85
5	Mudflat	Mud	1.50
7	High	Ref	2.40
8	High	Ref	2.39
9	Low	Ref	2.01
10	Low	Ref	1.99
11	High	Out	2.63
13	Low	Out	2.22
16	Low	Out	2.21
20	High	Out	2.55

Table 6. SET site elevations. RTK GPS survey data indicates mid elevations for the low marsh sites in the area directly outside the farmland. Sites 13 and 16 are at an elevation much higher than the other low marsh sites, but lower than the high marsh sites. Courtesy of the USGS.

The vegetation transects show that the location in the preserve was not a significant driver of the observed vegetation community structures. The location is more likely an arbitrary factor and its significance would have indicated the influence of an unmeasured variable, such as distance from the main flow of the Stillaguamish River or from a distributary channel, as distance from a channel is demonstrated to have an effect on vegetation community structure (Sanderson et al. 2000).

4 CONCLUSIONS

4.1 *Summary*

4.1.1 Sediment dynamics and NPP

The work completed during this study provides a first look into a long term estuarine restoration project taking place in the north Puget Sound at Port Susan Bay. This project addressed the current sustainability of the preserve under the effects of climate change and investigated the processes of sediment dynamics in the area from 2011-2013. The results of these initial surface elevation monitoring efforts in PSB indicated that the estuary gained significant surface elevation during the first sampling years in all but 3 of the 11 sites, with sediment accretion accountable for most of the increased elevation, and some lesser gains from other processes, such as in situ biomass buildup. The sites with a measured loss in surface elevations were 2 of the low marsh replicates in the north location, with evidence of erosional processes found in the area, finding evidence of this in terracing of the sediment banks near the SET locations. The third site to go against the overall trend of surface elevation gain was at SET 11 which showed no substantial gain or loss in elevation; evidence of a short term disturbance was found, and gains in sediment accretion at the markers did

not match the SET results. Overall, the work from this project indicates that the estuary is currently sustainable with a few locations gaining elevation at rates that are higher than the top end of some sea level rise projections. The short temporal period of this study was a limitation in determining accurate trends in sediment dynamics at PSB.

NPP results indicated that on average the preserve had significantly more productivity in the high marsh sites, with the high marsh site in the outside location being the most productive. I also found that the high and low marshes had varying NPP levels between the locations, with the low marsh being more productive than the high marsh in the north, against the overall trend of a more productive high marsh. Elevation may be a driver of NPP as hypothesized, but in conjunction with other unmeasured variables, such as distance to major channels, the relationship could not be significantly determined as sampled ($p=0.5$). The most productive site in the high marsh was in the outside location, and this site had the highest elevation and was located closer to several major distributary channels than other sites in the preserve (Figure 3 and Table 6).

Linking physical and biological variables with sediment dynamics yielded interesting results that were opposite of my predictions, with a significant negative trend between standing peak biomass (NPP) and sediment accretion and surface elevation change. The results indicated that as productivity increased, there was less sediment accretion and surface elevation change. It is possible that another variable, such as stem density, may be more important in sediment entrapment and elevation gain than what I predicted with overall standing biomass. Another potentially confounding variable was the persistence of standing vegetation during the winter. The low marsh sites in the north lose most of the

standing vegetation during the winter months, therefore not having stems present to entrap and hold material, likely becoming erosional until the next growing season.

4.1.2 Vegetation

Sampling of vegetation species and abundances across the Port Susan Bay preserve revealed how community structure in this estuarine system is influenced more by elevation than the connectedness of sampled sites. Elevation is correlated with many processes, such as flood frequency, salinity, and nutrient sources. More stress tolerant species should be present in areas with high salinity and frequent flooding, such as lower elevations, with shifts in community structure with increased elevation. Point-intercept (transect) and percent species cover (quadrat) sampling revealed that the marsh type (elevation) of each site is the main determinant of species presence and abundance. In the restoration area that has been historically separated from the rest of the system by levees, vegetation community structure was found to be apart from, but more similar to the low marsh than the high marsh, likely due to semi-permanent flooding, and salt water intrusion through the levee inside the restoration area, leading to conditions similar to the low marsh with regular flooding by saltwater. Outside the levees, high and low marsh sites were well separated, with the location in the preserve having little influence on the sampled community structure. These results matched my hypothesis of elevation being the main driver of community structures, and the farm having a unique structure due to its elevation and disconnection from the rest of the system.

The only site that did not have a community structure similar to the others of its type, was a low marsh site in the outside location (site 13); analysis placed this site between

the high and low marsh sites in the community ordination. The elevation data revealed that this site inhabits an elevation that falls between the other high and low marsh areas.

Examination of the species driving community structure showed that the low marsh outside site (site 13) shares similar species with both low and high marsh sites, and also has a higher abundance of *Scheonoplectus acutus* than was found in any of the other sampled sites. The findings from the elevation and species data further supports my hypothesis that elevation is a major determinant of community structure, with other variables such as salinity and flood frequency determined by the elevation.

4.1.3 Species influence on sediment dynamics

Primary productivity and vegetation sampling indicated that the low and high marsh site have very different community structures, with the low marsh being predominantly sedges (*Schoenoplectus americanus*) and the high marsh being a mix of mostly rushes and grasses with some *Schoenoplectus maritimus* (Figures 31 and 32, Table 4). The higher elevation sites exhibited more surface elevation gain than those in the lower elevations, with a negative correlation of NPP with the change in elevation (Figures 19 and 21). This may indicate that the smaller and more densely growing plant species found in the higher elevations (grasses and rushes) may entrap more sediment than the larger and sparser species (sedges) mainly found in the lower marsh (Figure 25). Further, ground observations indicated that high marsh species were more persistent during the winter, and therefore having greater potential sediment deposition in the high marsh during the winter and the absence of vegetation may cause erosion in the low marsh during that time.

4.2 Conclusion

Under current conditions, the Stillaguamish River estuary in Port Susan Bay is expected to persist with rising sea level predictions. The majority of the system shows surface elevation gains above the current rate of sea level rise in area, indicating the ability to persist under higher sea level rise scenarios and the potential for seaward expansion of the marsh. The long term results from this levee removal restoration project have not been determined at this time, though the predictions are for increased sediment deposition from the expansion of current distributary channels across the formally cut off restoration area, providing greater potential surface elevation gain throughout the estuary (Syvitski et al. 2005).

As elevations increase inside the restoration area, due to deposition from channel formation and the resulting flow of sediment into the lower elevation area, vegetation communities should shift to the new elevations accordingly, likely resulting in the establishment of high marsh vegetation species as the surface elevations equalize with the surrounding high marsh area (Cui et al. 2011). This would also increase productivity in the restoration area as the more productive high marsh species establish themselves, with the high marsh sites directly adjacent to the restoration area having the highest productivity measured in the preserve.

A project has been proposed for the dredging of the channel at South Slough in the northern region of the estuary and depositing that material into the restoration area. This would greatly accelerate the infilling of sediment taking place naturally and speed up the establishment of higher marsh vegetation in the restoration area (Cornu and Sadro 2002).

The return of river flow through the currently tidally driven South Slough, may also lead to increased deposition of material in the low marsh areas to the north, as the river is the main source of estuary building sediment. The shift to a less erosional low marsh, may also increase the presence of standing vegetation in that area during the winter months, and therefore lead to sediment deposition instead of erosion over those months.

The elevation of the soil surface has been tied to many estuary shaping processes (Cui et al. 2011). This project has also indicated that elevation is the driver of many processes within Port Susan Bay, having been shown to influence vegetation community structure, productivity, and a trend of potential influence on surface elevation dynamics. The elevation drives vegetation species distribution and abundances, and vegetation influences the deposition of sediment onto the surface, and therefore elevation change. This cycle is what maintains the equilibrium of estuarine surface elevations with sea level rise, and is important for the continued presence of the Port Susan Bay preserve and beyond. Alteration of this equilibrium, through either the loss of sediment sources or increased rates of sea level rise, above potential rates of sediment deposition, results in the decline of estuaries around the world.

Continued monitoring and expansion of the SETs into the farmland and other unmonitored areas is recommended to track the long term success of the levee removal restoration. During the early spring of 2014, monitoring was expanded with more SETs and feldspar markers installed within the restored farmland and a middle area between the outside and north location. Preliminary monitoring of those new feldspar markers show that inside the restored farmland, up to 7cm of sediment has accreted over 3-4 months.

This could be due to lower elevation of the restoration area and that a large landslide occurred in the upper river in the town of Oso, Washington soon after installation of those markers. The lower elevation of the farmland causes water to pool inside and deposit the suspended sediment after entering with high tide, more than likely at a rate higher than will be seen at other locations in the preserve. Combined with the large amount of material in the river from the landslide, high volumes of material were being deposited in that area. Deforestation practices increase landslide frequencies and in some locations now account for much of the overall sediment in rivers (Glade 2003). Storms and hurricanes are another potential driver of sedimentation in estuaries, pushing material from the ocean floor into the estuary (Turner et al. 2006). Though often tragic, these unpredictable sediment pulsing events may be important to the current sustainability of estuaries.

In conclusion, the trend in many estuarine systems around the world is of a decline in total surface area as a result of climate change, rising sea levels, and human modification (National Research Council 2012). The system in Port Susan Bay appears, so far, to be one of the exceptions to this trend, as the river has been relatively unmodified. Surface elevations are above sea level, and the outlook for further restoration efforts in the area is promising. One area of caution is still the levees landward of the preserve. With further increasing sea level rise, the estuary may be at risk of being squeezed against the much higher levee structures and eventually lost. Climate change also comes with many other consequences beyond rising sea levels, including changing weather patterns, storm frequencies, and temperatures, which can all impact estuarine vegetation, sediment dynamics, and the overall sustainability of the systems (National Research Council 2012,

Short and Neckles 1999). The persistence of estuaries, such as that in Port Susan Bay and other systems in the Puget Sound and beyond, requires continued long term monitoring that can be used to guide research and restoration efforts as they are needed, whether that is continued back setting of levees or the removal of other hydrological impediments to sustain these ecologically and monetarily important ecosystems.

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APPENDICES

Tables

Table 1. Fisher LSD contrast of mean yearly elevation change with location.

Table 2. ANOSIM of vegetation point intercept data, one-way analysis with marsh type.

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Table 6. ANOSIM of vegetation quadrat data, one-way analysis with location.

Table 7. SIMPER of vegetation quadrat data, one-way analysis with marsh type.

Table 1. Fisher LSD contrast of mean yearly elevation change with location.

Multiple Comparisons

Dependent Variable: Mean_Elv_Chg_Yr

LSD

(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
North	Outside	-.2925	.16242	.146	-.7435	.1585
	Reference	-.5200*	.13262	.017	-.8882	-.1518
Outside	North	.2925	.16242	.146	-.1585	.7435
	Reference	-.2275	.16242	.234	-.6785	.2235
Reference	North	.5200*	.13262	.017	.1518	.8882
	Outside	.2275	.16242	.234	-.2235	.6785

Based on observed means.

The error term is Mean Square(Error) = .035.

*. The mean difference is significant at the 0.05 level.

Table 2. ANOSIM of vegetation point intercept data, one-way analysis with marsh type.

Factor: Marsh Type

REST

HIGH

LOW

Global Test

Sample statistic (Global R): 0.81

Significance level of sample statistic: 0.3%

Number of permutations: 999 (Random sample from 5775)

Number of permuted statistics greater than or equal to Global R: 2

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Actual Permutations	Number >= Permutations	Observed
REST, HIGH	1	2.9	35	35	1
REST, LOW	0.537	2.9	35	35	1
HIGH, LOW	0.796	2.9	35	35	1

Table 3. ANOSIM of vegetation point intercept data, one-way analysis with location.

Factor: Location

REST

NORTH

OUT

REF

Global Test

Sample statistic (Global R): 0.665

Significance level of sample statistic: 0.3%

Number of permutations: 999 (Random sample from 34650)

Number of permuted statistics greater than or equal to Global R: 2

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Actual Permutations	Number >= Permutations	Observed
REST, NORTH	0.75	6.7	15	15	1
REST, OUT	1	2.9	35	35	1
REST, REF	0.643	6.7	15	15	1
NORTH, OUT	0.667	10	10	10	1
NORTH, REF	-0.5	100	3	3	3
OUT, REF	0.25	20	10	10	2

Table 4. SIMPER of vegetation point intercept data, one-way analysis with marsh type.

SCAM=*Schoenoplectus americanus*, DISP=*Distichlis specata*, DECE=*Deschampsia cespitosa*, LI=Litter, TYAN=*Typha augustifolia*, SYSU=*Symphyotrichum subspicatum*, SCMA=*Schoenoplectus maritimus*, POAN=*Potentilla anserina*, JUBA=*Juncus balticus*, JUEF=*Juncus effuses*, GRIN=*Grindelia intergrifolia*, ATPA=*Atriplex patens*, TRMA=*Triglochin maritimum*.

Group REST

Average similarity: 64.21

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCAM	10.26	58.07	4.94	90.43	90.43

Group HIGH

Average similarity: 54.67

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
DISP	7.05	14.77	4.41	27.02	27.02
SCAM	5.34	13.07	20.79	23.91	50.92
DECE	2.78	5.18	2.78	9.47	60.40
LI	3.46	4.94	6.39	9.03	69.43
TYAN	3.57	4.93	0.90	9.02	78.45
SYSU	2.03	3.03	2.61	5.54	83.99
SCMA	3.23	2.79	0.74	5.10	89.09
POAN	1.60	1.76	0.79	3.23	92.31

Group LOW

Average similarity: 51.12

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCAM	9.47	32.02	3.25	62.63	62.63
SCMA	5.21	16.00	4.56	31.30	93.93

Groups REST & HIGH

Average dissimilarity = 71.91

	Group REST	Group HIGH				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
DISP	2.29	7.05	9.60	1.46	13.35	13.35
SCAM	10.26	5.34	9.01	2.66	12.54	25.89
TYAN	0.00	3.57	6.57	1.45	9.14	35.03
LI	0.00	3.46	6.47	1.26	8.99	44.02
SCMA	0.00	3.23	5.89	1.03	8.19	52.21
DECE	0.00	2.78	5.04	2.81	7.00	59.21
JUBA	0.00	2.10	3.92	0.94	5.45	64.67
SYSU	0.00	2.03	3.78	1.50	5.25	69.92
JUEF	0.25	1.95	3.51	0.62	4.89	74.81
SCAC	0.00	1.75	3.32	0.84	4.62	79.43
GRIN	1.68	0.00	2.75	0.95	3.82	83.25
POAN	0.25	1.60	2.70	1.20	3.76	87.01
LOCO	0.00	1.31	2.36	0.95	3.28	90.29

Groups REST & LOW

Average dissimilarity = 53.35

	Group REST	Group LOW				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
SCMA	0.00	5.21	14.39	1.78	26.98	26.98
SCAC	0.00	3.94	9.21	0.67	17.26	44.24
SCAM	10.26	9.47	7.90	1.51	14.81	59.05
DISP	2.29	0.75	5.36	1.07	10.05	69.10
GRIN	1.68	0.00	3.77	0.94	7.07	76.17
TRMA	0.00	0.91	2.58	1.20	4.83	81.00
ATPA	1.00	0.00	2.26	0.95	4.24	85.24
LI	0.00	0.80	2.08	1.30	3.90	89.13
TYAN	0.00	0.82	1.91	0.67	3.57	92.70

Groups HIGH & LOW

Average dissimilarity = 63.64

	Group HIGH	Group LOW				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
DISP	7.05	0.75	10.53	2.45	16.55	16.55
SCAC	1.75	3.94	7.10	1.04	11.15	27.71
SCAM	5.34	9.47	6.95	1.28	10.92	38.63
SCMA	3.23	5.21	5.73	1.29	9.01	47.64
TYAN	3.57	0.82	5.24	1.41	8.24	55.88
DECE	2.78	0.00	4.49	2.87	7.05	62.93
LI	3.46	0.80	4.45	0.96	6.99	69.92
JUBA	2.10	0.58	3.47	1.14	5.45	75.38
SYSU	2.03	0.00	3.36	1.51	5.27	80.65
JUEF	1.95	0.00	2.96	0.55	4.65	85.30
POAN	1.60	0.00	2.58	1.25	4.06	89.36
LOCO	1.31	0.00	2.10	0.95	3.30	92.66

Table 5. ANOSIM of vegetation quadrat data, one-analysis with marsh type.

Factor: Marsh Type

REST

HIGH

LOW

Global Test

Sample statistic (Global R): 0.404

Significance level of sample statistic: 0.1%

Number of permutations: 999 (Random sample from a large number)

Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

	R	Significance	Possible	Actual	Number >=
Groups	Statistic	Level %	Permutations	Permutations	Observed
REST, HIGH	0.536	0.1	Very large	999	0
REST, LOW	0.124	0.1	Very large	999	0
HIGH, LOW	0.495	0.1	Very large	999	0

Table 6. ANOSIM of vegetation quadrat data, one-way analysis with location.

ANOSIM – Quadrat Data

Analysis of Similarities

One-Way Analysis

Factor: Location

REST

NORTH

REF

OUT

Global Test

Sample statistic (Global R): 0.235

Significance level of sample statistic: 0.1%

Number of permutations: 999 (Random sample from a large number)

Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
REST, NORTH	0.376	0.1	Very large	999	0
REST, REF	0.247	0.1	Very large	999	0
REST, OUT	0.357	0.1	Very large	999	0
NORTH, REF	0.126	0.9	Very large	999	8
NORTH, OUT	0.162	0.6	Very large	999	5
REF, OUT	0	43.5	Very large	999	434

Table 7. SIMPER of vegetation quadrat data, one-way analysis with marsh type.

SCAM=*Schoenoplectus americanus*, DISP=*Distichlis specata*, DECE=*Deschampsia cespitosa*, LI=Litter, TYAN=*Typha augustifolia*, SYSU=*Symphyotrichum subspicatum*, SCMA=*Schoenoplectus maritimus*, POAN=*Potentilla anserina*, JUBA=*Juncus balticus*, JUEF=*Juncus effuses*, GRIN=*Grindelia intergrifolia*, ATPA=*Atriplex patens*, TRMA=*Triglochin maritimum*.

Group REST

Average similarity: 38.12

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCAM	15.22	35.59	1.15	93.37	93.37

Group HIGH

Average similarity: 36.92

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
DISP	48.81	31.87	0.89	86.30	86.30
JUEF	3.90	1.64	0.29	4.45	90.76

Group LOW

Average similarity: 38.47

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCAM	16.91	28.87	1.17	75.04	75.04
SCMA	5.00	5.33	0.35	13.85	88.90
JUEF	6.15	4.16	0.36	10.82	99.71

Groups REST & HIGH

Average dissimilarity = 91.54

	Group REST	Group HIGH				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
DISP	1.86	48.81	46.78	1.40	51.10	51.10
SCAM	15.22	4.12	18.76	1.06	20.50	71.60
JUEF	0.00	3.90	5.70	0.55	6.22	77.83
TYAN	0.00	2.79	4.98	0.31	5.44	83.27
SCMA	0.00	2.21	4.48	0.36	4.90	88.17
GRIN	3.58	0.00	3.53	0.37	3.86	92.02

Groups REST & LOW

Average dissimilarity = 67.98

	Group REST	Group LOW				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
SCAM	15.22	16.91	31.07	1.35	45.71	45.71
SCMA	0.00	5.00	13.03	0.62	19.16	64.87
JUEF	0.00	6.15	11.30	0.66	16.63	81.50
GRIN	3.58	0.00	5.14	0.39	7.56	89.06
DISP	1.86	0.39	3.17	0.53	4.66	93.72

Groups HIGH & LOW

Average dissimilarity = 88.79

	Group HIGH	Group LOW				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
DISP	48.81	0.39	42.55	1.37	47.93	47.93
SCAM	4.12	16.91	18.02	1.14	20.29	68.22
JUEF	3.90	6.15	8.52	0.83	9.59	77.81
SCMA	2.21	5.00	7.71	0.67	8.69	86.50
TYAN	2.79	0.00	4.11	0.32	4.63	91.13