ABSTRACT

COASTAL SQUEEZE OF VEGETATION ZONES IN THE LOS CERRITOS WETLANDS: THE EFFECT OF SEA LEVEL RISE

By

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This project assesses the elevation of several vegetation zones of the Los Cerritos Wetlands in Southern California to determine the possible effects of sea level rise on the salt marsh vegetation, the foundation of coastal salt marsh ecology. Steamshovel Sough in the Los Cerritos Wetland contains ideal habitat for the project. This coastal salt marsh is unique in that it abuts artificial elevation gradients of urban development on all sides. The confined nature of the wetland restricts its ability to adjust to future sea levels, a process known as coastal squeeze, which calls the sustainability of this scarce ecosystem into question. In-situ surveying of indicator species Parrish's Glasswort and Pacific Cordgrass (*Arthrocnemum subterminale* and *Spartina foliosa*) revealed the habitat elevations above sea level. Modelling various sea level rise scenarios using the habitat ranges determined through in-site surveying reveal expected future habitat zones. Los Cerritos Wetland has a notable susceptibility to sea level rise because of topographic convolutions created by local urban development. One and two foot sea level rise scenarios project substantial zone shifts resulting in pronounced winners and losers. The results here highlight the delicacy of the marsh and its intimate relationship to sea level,

and hold a powerful utility to restoration project managers seeking to create a salt marsh that reflects the natural distribution of various habitats and which possesses longevity in the face of the changing environment.

COASTAL SQUEEZE OF VEGETATION ZONES IN THE LOS CERRITOS WETLANDS: THE EFFECT OF SEA LEVEL RISE

A THESIS

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INTRODUCTION

Urban development dominates the landscape along the southern California coastline. The patchwork of developed and undeveloped land delineates a boundary where anthropogenic landscapes end, and undeveloped, "natural" landscapes begin. As populations grow, it is common for new developments to claim untouched landscape along this boundary, resulting in the elimination of native undeveloped landscapes and the expansion of development.

Coastal areas are becoming more densely populated and have some of the fastest growing populations (McGranahan, Balk, and Anderson 2007). As population increases in coastal communities, the remaining natural environments along the coast are at risk of succumbing to the threat of mounting anthropogenic disturbance. These threats include pollution, the introduction of exotic invasive species and further development of the natural landscape. As a result, coastal wetland ecosystems are some of the most threatened in the world (Radeloff et al. 2005; Agardy et al. 2005). Today, approximately 91% of California's historic wetland area is developed or disturbed (Lester 2010). These habitats continue to face a substantial reduction in viability because of constant urbanization along the wildland urban interface (Nicholls et al. 2007).

In addition to anthropogenic threats, coastal wetlands face a threat from changing sea levels. Sea level rise (SLR) is an undeniable fact (Parris et al. 2012; Church et al.

FIGURE 1. Steamshovel Slough in LCW and the artificial elevation gradients that confine the marsh, which offers no habitat for migrating vegetation zones.

2013). The coastal ecosystem of the salt marsh has evolved an inseparably close relationship relative to its elevation sea level (Pennings and Callaway 1992). The gradual rise of mean sea level (MSL) influences key variables of the ecosystem, exhibiting stresses on the species in the salt marsh. This stress forces these ecosystems to migrate towards higher elevation in order to maintain their location relative to the tides. In wetlands subject to the pressure of urbanization, the rising sea level may present a compound threat as the migrating ecosystem encounters artificial elevation gradients like sea walls, river channels, streets or infrastructure (Torio and Chmura 2013) (Fig 1). The

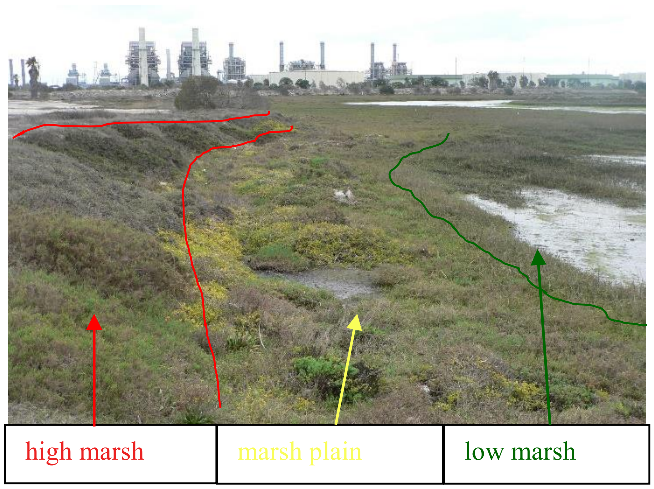

FIGURE 2. Salt marsh zones are constricted by the artificial elevation gradient in Steamshovel Slough, this is the process of coastal squeeze at work.

migrating vegetation zones may possibly move into a location where the topographic relief reduces the zone's habitable space. The influence that artificial elevation gradients have on the natural ability of coastal salt marsh to migrate away from rising sea level is referred to as coastal squeeze (Fig 2).

Coastal wetland ecosystems possess several intrinsic values, each of which highlights the necessity for anthropogenic support in light of introduced threats. If left undisturbed, these natural features produce valuable wetland services in perpetuity. Mitsch and Gosselink (2000) suggest a broad valuation of coastal wetlands based on nearby populations, the contribution of the wetland to the biosphere, and the effects or services of biological populations. The southern California salt marsh supports a range of endangered or rare species. A large macrophyte community creates an environment with great hydrologic conductivity that stores and filters water, nitrogen and carbon very efficiently (Brix 1997). California salt marshes provide habitat for migratory birds on the

Pacific Flyway during spring and fall months and provide resident fish populations with rookeries. These ecosystems also hold aesthetic, psychological and spiritual value too many (Boyer and Polasky 2004). In California, only 29 of these ecosystems still exist, obligating human protection (Zedler et al. 1999).

Los Cerritos Wetlands

Straddling the border between the cities of Long Beach and Seal Beach in southern California is the Los Cerritos wetland (LCW), (Fig. 3). This wetland complex lies at the mouth of the San Gabriel River. The historic extent of Los Cerritos Wetlands was approximately 2400 acres. Today slightly less than 600 acres remain undeveloped, and only about 100 acres are healthy coastal salt marsh. LCW exists as a disturbed but natural pocket of wetland among a sea of buildings and roads. The vast majority of LCW abuts residential and commercial developments. Residential neighborhoods of Long Beach and Seal Beach mark the northern and southern/southeastern limits of the wetland respectively. A small section of the wetland, affectionately referred to by some as the "jewel of Long Beach," is relatively unscathed despite its encompassment by artificial elevation gradients. Named Steamshovel Slough, this region of coastal salt marsh occupies approximately 60 acres between Pacific Coast Highway to the west, and Studebaker to the east. The inset in FIGURE 3 parameterizes Steamshovel Slough. Artificial elevation gradients built for the Cerritos flood channel to the north and oil operations to the south confine Steamshovel Slough .

Steamshovel Slough makes an excellent site for research focused on protecting the longevity of urban wetlands. Given the location of this marsh adjacent to heavily developed areas, and the potential impact of future sea level rise, this moderately healthy marsh is of prime concern to environmental protection services.

The goal of this research is to define better the expected changes of vegetation zones in a coastal salt marsh due to SLR. This study will map the elevation of surveyed vegetation species that best represent communities of salt marsh vegetation and analyze them in ArcGIS to address three essential questions regarding the marsh's response to SLR. First, what degrees of sea level rise will have the greatest effect on the elevation based vegetation zones? Second, what vegetation zones stand to lose or gain the most habitat with the rising sea level and is there a facet of coastal salt marsh ecology that speaks to the best methods for sustaining the environment in the face of sea level change? Third, is there a facet of coastal salt marsh ecology that may be re-created by restoration management in order to construct a resilient environment in the face of sea level change? The answers to these questions will help restoration managers to create a wetland ecosystem that is healthy, adaptive, easy to manage, and functional well into the future.

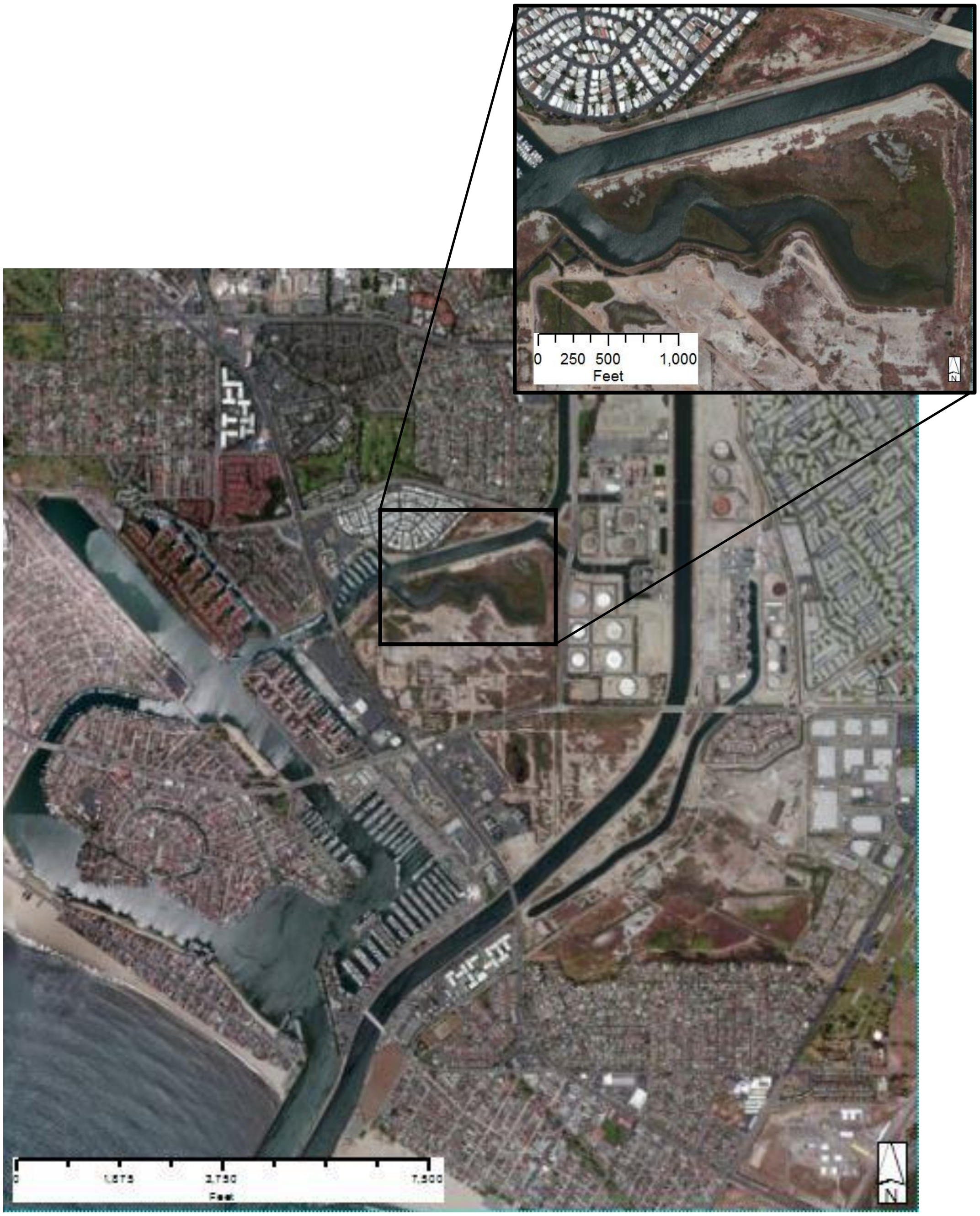

FIGURE 3. The salt marsh, Steamshovel Slough, is located within the patchwork of city streets, industrial complexes and residential neighborhoods. It is at the absolute northerly extent of Los Cerritos wetlands.

CHAPTER 2

LITERATURE REVIEW

Coastal Squeeze

Coastal squeeze occurs when coastal salt marsh habitat is lost due to SLR. The process is exaggerated in confined ecosystems. A confined ecosystem is defined as a natural habitat that is encompassed by urban development. As previously described, LCW has a distinct wild land urban interface around 100% of the periphery and is, therefore, considered a confined ecosystem.

With an understanding of the importance of elevation relative to sea level in wetland ecology and considering confined ecosystems like LCW, SLR assumes a much more threatening role. As sea level rises, the plant zones along the area of tidal influence migrate inland towards higher elevation (Nicholls and Mimura 1998; Nicholls, Hoozeman, and Marchand 1999; Nicholls et al. 2007; Feagin et al. 2010; Torio and Chmura 2013). Natural unconfined ecosystems exhibit this dynamic equilibrium in the face of rising sea level, which provides longevity to the vegetation zones (Cahoon, Reed, and Day 1995). Confined ecosystems lack the available landward space for vegetation zones to migrate inland. A confined salt marsh migrating inland in response to rising sea level will encounter the artificial elevation gradients of urban development. Whether confined by levees, embankments for raised roadways, or elevated building foundations, urban development will halt the inland migration of salt marsh (Nicholls, Hoozemans, and Marchand 1999). As a result, the rising sea levels “squeeze” the coastal salt marsh and the plant zones. The zones collapse, the ecosystem does not migrate and the invaluable ecological services of the wetland and the habitat for countless species including several rare and endangered species is lost to the waves. Research regarding the ability of the salt marsh habitat to exist along artificial elevation gradients presented by urban development has been performed in attempt to create a coastal squeeze index based on the percent slope of the inland habitat in the path of the migrating marshland and the imperviousness of the soil (Torio and Churma 2013). The primary purpose of their research was to dispel some of the ambiguity of the concept of coastal squeeze, and develop and categorize the degree of risk to coastal ecosystems.

Coastal Squeeze in Los Cerritos Wetland

Steamshovel Slough exemplifies the process of coastal squeeze in several areas (Fig 4). The condensed zonation of the marsh is visible in this image. The high marsh upper boundary is demarcated by the location of *Arthrocnemum subterminale* (dark vegetation growing on the exaggerated slope) and the lower boundary is demarcated by the lowest occurrence. The monotypic stands of cord grass to the right of the image stand in stark contrast to the variety of species throughout the marsh plain to the left and the mud flats to their right. The width and area occupied by the low marsh is typical of the width of the zone throughout the marsh. In an unconfined environment, the vertical increase from low marsh to high marsh is much more gradual. In such a case the zones occur throughout a wider region. Here, the marsh plain and high marsh appears squeezed down to a faction of the natural area because of an artificial gradient.

The artificial elevation gradient along the northern boundary is less acute, either because of erosion or perhaps because of the engineering of the Cerritos channel

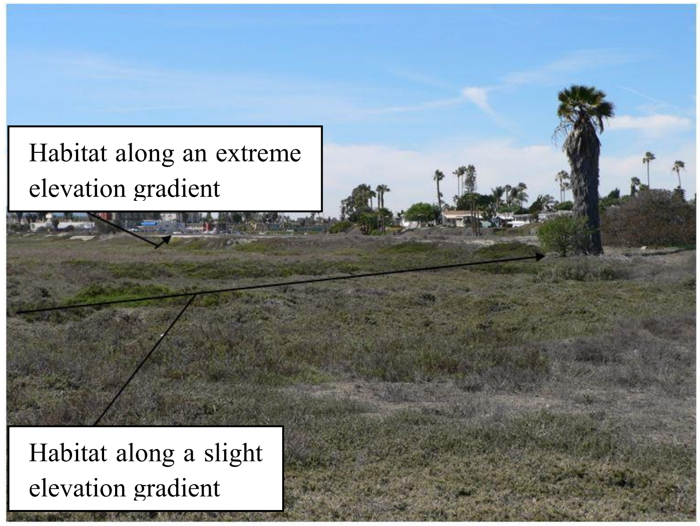

FIGURE 4. The difference in habitable area between elevation gradients is visible here in Steamshovel Slough

containing walls. In the foreground of this image, *Arthrocnemum subterminale* appears much further into the marsh plain along a gradual elevation gradient, while in the background of the image *Arthrocnemum subterminale* can be seen strictly at the artificial elevation gradient. The topography with the gradual slope coincides with the high marsh habitat elevation. Therefore, a gradual sloping topography through habitat range allows more lateral space to be occupied by the species, while in the background the steep slope travels through the habitat elevation range of the species in a much smaller lateral area, leaving a smaller habitable zone. The habitat in the background of this image reveals coastal squeeze occurring in the high marsh. Coastal squeeze is apparent throughout Steamshovel Slough today; rising sea level will only exaggerate this effect.

Sea Level Rise

Historic Sea-Level Rise

Historic sea level changes provide data that can be used to predict future SLR scenarios. The degree of SLR expected in the future inform policy and land management, and is therefore fundamental when assessing the possible outcomes of landscapes that hold significant social, economic and environmental value.

Global historical sea level rise has been widely researched. Geologic and fossil records reveal a sea level that is in a perpetual state of flux, which has occurred at varying rates. Salt marsh depositional environments offer proxy data applicable in the creation of high-resolution temporal maps of recent sea level locations. Sediment cores from these marshes contain depth-sensitive Foraminifera that are biologically constrained to very specific ocean depths. Retrieving and dating these protozoa offer accurate indications of prehistoric ocean depths. This data has indicated that sea levels have rarely been static in recent geologic history.

Two centuries of in-situ recordings of relative sea level location has contributed to understanding the most recent rate of mean sea level (MSL) rise. Douglas (1991) collected this historic documentation from various locations around the globe. The research excludes data from active tectonic boundaries with components of vertical motion, data that was less than 80% complete, or data spanning 50 years of documentation or less. This investigation indicates a recent global rate of MSL rise of 1.7 mm/year ± .3mm/yr. The observable history of SLR provides a mechanism to predict future SLR scenarios and the effect they may have on the modern world.

Contemporary Sea-Level Rise and Observed Acceleration

Space-based Earth observation and monitoring satellites have recently been applied by researchers to evaluate SLR. Data from historic tide gauge measurements and satellite altimeter readings have been coupled with satellite imagery to reveal that SLR has started to accelerate in recent decades (Church and White 2006, 2011; Willis et al. 2010). Church and White (2011) combine historic in-situ measurements with satellite altimeter data from any area of coverage overlap between the Jason I & II and TOPEX/Poseidon which is a joint effort between NASA and CNES. These satellites had the ability to observe ocean surface topography at any location on the planet. This analysis has shown SLR rates between the 1940s and 2010, ranging from 2-3 mm/year. This represents a rate at the upper end of the common SLR scenarios. Several variables are posited as possible non-climate related contributors to the variability in SLR estimations. For example, the amount of water contained behind dams built since 1950 potentially store the equivalent of 30mm of sea level, thus damping the amount of SLR observed from climatological factors.

Satellite altimeter measurements have observed regional variability in the rates of SLR. The degree of SLR varies depending on the specific point on Earth. Scavia et al. (2002) and Tebaldi, Strauss and Zervas (2012) report the measurements of sea level rise from various locations around the planet to obtain a global mean sea level rise rate. The global estimates parallel the observed sea level rise rates in records for California (Parris et al. 2012).

Defining Sea Level Rise for the 21st Century

The extrapolation of multiple variables with climate influence to the end of the century creates a vast amount of uncertainty for climate sciences. Scientists evaluating the total amount of SLR must cope with this variable of uncertainty. The creation of multiple scenarios, each one parameterizing a range for sea level rise given the result of a set of fluctuating climate influence variables allows for a comprehensive approach to SLR management.

The recent acceleration of SLR rates demands an appraisal of the degree of future SLR, especially considering recent research indicating that climate warming will contribute to a thermal expansion of seawater, which will cause sea level to rise for a minimum of three centuries (Church et al. 2013). This “guaranteed” SLR due to thermal expansion is referred to as “The Climate Change Commitment” (Wigley 2005). Quantifying SLR for the future relies heavily on model simulations. In order to quantify sea level rise in a tangible timeframe, models typically produce estimates for SLR for the end of the 21st century. Contemporary models from the Intergovernmental Panel on Climate Change (IPCC) and the National Ocean and Atmospheric Administration (NOAA), which reference a multitude of refereed scientific journals, estimate a global range of sea level rise possibilities between 38 cm – 2 m (Pteffer, Harper, and O’Neel 2009; Vermeer and Rhamstorf 2009; Parris et al. 2012; Church et al. 2013).

Variables in the SLR equation include the degree of atmospheric heating, the input of melt water from melting glaciers and ice caps and the application of mitigation techniques and their influence. Scenario sets are advantageous for decision makers. For example, under the threat of a meter of SLR or more, the plans for constructing a nuclear power plant would undoubtedly reference the worst-case scenario of SLR. The construction of a baseball diamond or a public restroom creates a much smaller degree of vulnerability and, therefore, may be informed by a best-case scenario.

Much focus from academics and from government and private agencies has been placed on creating accurate scenario ranges. The degree of uncertainty in several variables renders a universally agreed upon scenario range impossible. The IPCC's assessments of SLR apply contributions from dozens of scientists and trusted academics, but, due to the levels of uncertainty in the multiple variables, even this well published multi-national team of scientists faces dissenting opinions. The 2013, 5th assessment of the Intergovernmental Panel for Climate Change projected scenarios for sea level rise ranging from 28 cm to 98 cm (Church et al. 2013). No upper limit for the worst-case scenario is explicitly stated due to the uncertainty regarding the additional input of melt water, but they do state with moderate confidence that the high end of sea level rise could reach 1.7 meters. This value is based on the suggestion that the break-up of aquatic sections of the West Antarctic ice sheet may add several tenths of a meter to the upper limit of SLR at an undetermined rate. The National Oceanic and Atmospheric Administration defines several scenarios expected by the year 2100. Parris et al. (2012) create four scenarios of SLR ranging from a minimum of 20 cm to 2 m. The scenarios are based on a 90% confidence interval. Predictions for SLR along the California coast are expected to follow this rate.

Tidal Datum

The vertical range of the tides and the frequency of high and low cycles varies based on geographic location. Southern California experiences a mixed, semi-diurnal tide fluctuation, which is defined by two high and two low tides of different magnitudes every lunar day. The minimum and maximum daily tide are dependent upon the orientation of the Sun, Moon, and Earth. The upper and lower limit of these daily tides fluctuate over the solar year but range from -.98 and 6.95 feet. Tidal data for this research are provided by NOAA's tide station 9410680. The zero elevation for this data station is also the benchmark zero elevation for the North American Vertical Datum of 1988.

Salt Marsh Ecology

Salt Marsh Zonation

Southern California salt marsh habitat occurs along the narrow swath of land that intersects the tidal wax and wane of the Pacific Ocean. The salt marsh is an ecosystem within the coastal wetland. It is an ecotone, a transition area between two distinctly separate biomes. It separates upland landscapes, such as coastal sage scrub, alkali meadows and oak woodlands from the marine ecosystems. A large portion of the healthy Los Cerritos Wetland habitat is coastal salt marsh. The coastal salt marsh is host to a variety of halophytic plant species that grow in distinct patterns. These plant zones grow in patchwork mosaics of varying size that seem to be spatially organized (Zedler 1996; Pennings and Callaway 1992; Zedler et al. 1999; Noe and Zedler 2001a; Silvestri, Defina, and Marani 2005). Some vegetation zones are monotypic stands that begin and end within several centimeters of elevation while other stands have less distinct boundaries along assemblages of species.

Elevation above sea level throughout the tidal range acts as a controlling force to the zonation of salt marsh vegetation (Zedler 1996; Pennings and Callaway, 1996; Zedler et al. 1999). For example, edaphic chemistry is directly related to the duration of salt-water inundation. Salinity and other edaphic conditions change gradually along the interface of tidal influence, while the elevation of plant species zones have clear boundaries that are consistent with specific elevations above sea level (Pennings and Callayway 1996).

Research has identified key ecological factors in the success of salt marsh halophytes. In controlled laboratory conditions, Noe and Zedler (2000) attempted to define the abiotic influences of southern California salt marsh halophyte growth. As expected, sunlight period, soil salinity, soil moisture, and temperature each had varying effects on the germination period and growth rate of the multiple species tested, but none of these factors was seen as having a more direct impact on the location of vegetation zones. In a subsequent study, Noe and Zedler (2001a) elucidated the factors controlling plant zone establishment by researching seeding success from 27 different species in varying ecological conditions in three separate southern California salt marshes over two years. They deciphered the elevation of the fundamental niche for several species. After testing ecological influences like salt water duration, sunlight period and salinity, no primary ecological control was found to have a determining role in the locations of each species. Contrary to their expectations, it was found that plant zone elevations was strongest control on zone location and these zones were marsh specific. In other words, no ecological control could be related to vegetation location, other than elevation above sea level. In their research, models, and in literature review Silvestri, Defina, and Marani (2005) were unable to find any spatial correlation between the location of vegetation zones, soil salinity, or even tidal zone. These findings indicate that the best reference variable for the location of vegetation zones is simply elevation above sea level. It is stated that the relatively low vegetation biodiversity in the marsh, and the pronounced variation in ecological factors throughout the 0-3 meters of elevation change, is enough to explain the zonation of coastal salt marshes (Zedler et al. 1999). It is fundamental in this research to note that elevation based zonation of coastal salt marsh species is the most persistent model for understanding the spatial patterns exhibited by coastal salt marsh vegetation.

Defining the High Marsh

The high marsh zone is defined as the location at the absolute upper reach of the tidal influence of the marsh (Zedler et al. 1992) (Fig 5). At the upper extent, the high marsh gives way to transition zone and various upland habitats. At the lower extent it gives way to the marsh plain along a clearly delineated habitat range. In their research into the zonation of salt marsh vegetation in a southern California marsh Zedler et al.

FIGURE 5. The foreground is a large individual of *Arthrocnemum subterminale,* the indicator species for the high marsh

(1999) determine that *Arthrocnemum subterminale* (Parrish's Glasswort) adheres to elevation very well, making it an excellent indicator for demarcating the region. *Arthrocnemum subterminale* is a perennial shrub that grows low to the ground, large plants reaching around 6 feet in width. The base of the plant is woody while fleshy pickle-shaped jointed sections extend to around 2 feet tall. Inflorescences are very small and impossible to see unless viewed from within a few feet.

Defining the Marsh Plain

A relatively wide and gradual slope occurs between the low marsh and the beginning of the high marsh. It ranges from around 150 feet to nearly 1100 feet across depending on the section of the marsh, while the elevation change is often less than one foot. This is the "marsh plain." The marsh plain is distinct in every location of the marsh except for a small area one-third from marsh opening. Below the elevation of the lowest occurance of *Arthrocnemum subterminale* lies what Zedler et al. (1999) call the "marsh plain." They recommend identifying the marsh plain be based on the presence of *Salicornia pacifica,* (Common Pickleweed). However, the marsh plain can be defined based on its location between the boundaries of the high and low marsh, and, as such ,an indicator species is not necessary.

Defining the Low Marsh

Spartine foliosa (Pacific Cordgrass) is the only marker for the elevation zone of the low coastal marsh (Zedler, 1996; Pennings and Callaway 1994). This perennial grass grows_from single stalks that reach around two feet, although it can grow over twice this height. The leaves alternate and stem directly off the stalk; they have a slight u-shape and end with a shallow angle tip. Some leaves appear to have light purple edges and veins. The leaves of the grass have a textured sinewy feel. This is the only species that can survive at the lowest reaches of the low marsh zone, as it can withstand repetitive and prolonged salt-water inundation (Fig 6). It does, however, occasionally appear as part of the large assemblage of species in the marsh plain. Because this species is only occasionally found outside of a very discernible area, the species is only used as an indicator species of elevation zones where it is very distinctly surviving in monotypic stands. Monotypic stands of *Spartina foliosa* are easily identifiable because the low elevation of the habitat always coincides with the mud flats and the upper end of the habitat is always a distinct transition into the marsh plain assemblages. These zones always parallel the waterline and are always on the bayward edge of the marsh. The only locations in a marsh that deviate from vegetation stands that run parallel to the waterlines are in areas of topographic heterogeneity. For example, *Spartina foliosa* thrives along subtle channels formed by retreating tides.

FIGURE 6. A large stand of *Spartina foliosa*. The indicator species for the low

High Value Species

The Los Cerritos Wetland complex is home to several state and federally endangered species. *Salicornia pacifica* is a denizen of the coastal salt marsh transition zone and it is invaluable to the endangered Belding's Savannah Sparrow (*Passerculus sandwichensis beldingi*), which nests almost entirely among its leaves (Fig 7). Up to 50

FIGURE 7. The Belding's Savannah Sparrow in Steamshovel Slough, just prior to breeding season

pairs are residents nesting in Los Cerritos Wetlands. *Distichlis spicata* grows throughout the high marsh and transition zone. This grass species is essential to the endangered Wandering Skipper butterfly, *Panoquina errans*. The Wandering Skipper's larvae eat only the leaves of the *Distichlis spicata*. The federally and state endangered California Least Tern (*Sterna antillarum browni*) has been documented foraging in open waters in Los Cerritos Wetlands. The Pacific Green Sea-turtle, *Chelonia mydas,* has established a resident population amongst the artificially warm waters produced by the freshwater outflow of a local power plant into the San Gabriel River. LCW is well north of the species natural habitat range. The extensive list of rare, threatened and endangered species living throughout the Los Cerritos complex lends a substantial degree of ecological value to the wetland system. In addition to several special status animals at home in the Los Cerritos Wetland, the habitat is home to at least seven different plant species that are on the California Native Plant Society list for rare plants. These species include *Lycium californicum, Sueda esteroa* and *Centromadia parryi ssp. australis*, (California Box Thorn, Estuary Sea-blite, and Southern Tarplant) all of which are naturally occurring residents of LCW.

Support for the Los Cerritos Wetland

National, state and local political support provides a strong foundation for the continuity of restoration efforts. National policies such as section 404 of the Clean Water Act, which places restrictions on the availability of permits for dumping, dredging and construction, help protect coastal wetland ecosystems by mitigating negative anthropogenic impacts. Southern California is now home to a number of wetland protection programs. The California Environmental Quality Act (CEQA) took a large step towards protecting remaining wetlands and restoring damaged ecosystems when it mandated analysis of any possible environmental impact from coastal development (Parrish et al. 2012). The management of LCW consists of several different owners and leasses between the cities of Seal Beach and Long Beach. The Los Cerritos Wetland Authority (LCWA), developed in 2006, manages political relationships between the cities and the land owners and organizes and manages a comprehensive restoration plan.

Today the LCWA owns approximately170 acres of the 600-acre complex, including the entire Steamshovel marsh.

The local Southeast Area Development and Improvement Plan (SEADIP) supports Los Cerritos on a more intimate scale. SEADIP manages the use and development of the remaining land surrounding the Los Cerritos wetland and appropriates mitigation credits for developers to specific sections of the marsh in response to any disruption of habitat (City of Long Beach 2006). Local policy and supportive communities in Long Beach have actively supported the wetland and routinely rejected large development proposals, including those for large, multi-storied high-end apartment buildings and a proposal for a Home Depot at the eastern arm across the street from Steamshovel Slough. Support like this allows California the opportunity to protect the remaining shreds of natural wetlands it has left. The LCW is a beneficiary of national, state and local policy. Restoration programs such as the LCWA guarantee a degree of protection in the future

The conceptual plans that exist for the LCWA acknowledge SLR and the need to adapt to it. They do not address any specific impacts SLR will have on the zonation of the various microhabitats or the absence of possible peripheral wetland ecosystems due to the interface with urban development. This research, supported by the aforementioned scientific research, and applying provides elevations for modern vegetation zones and models expected changes in marsh ecology.

CHAPTER 3

METHODS

A common methodology for identifying elevation of plant zones, and the foundation for the methodology applied here-in, is the application of topographic surveying techniques and the use of geographic information systems (GIS). Zedler et al. (1999) applied series of elevation measurements throughout a marsh with a high quality surveying tool to trace elevation along extensive transects, some almost a kilometer in length, to determine the abundance and spatial patterns of coastal salt marsh vegetation zones. The results defined several characteristics of southern California salt marsh used in this study. Sylvestri, Defina, and Marani (2005) used GPS/surveying equipment in their spatial analysis of a coastal salt marsh in Italy. Such methods proved successful in determining elevations ranges of indicator species within similar environments.

The methodology applied here draws on these previous studies. The most common SLR scenarios posited by NOAA and the IPCC inform the various degrees of modelled sea level change. The degrees of SLR are discussed in subsequent pages. Previous research reveal basic topographic surveying of indicator species designate elevation of vegetation zones above sea level. *Spartina foliosa* (Pacific Cordgrass) most accurately represents the low marsh, while *Arthrocnemum subterminal* (Parrish's Glasswort) best defines the high marsh (Zedler et al. 1999). ArcGIS was used to perform the spatial analysis of the data collected from surveying and models three SLR scenarios.

Establishment of Sea Level

All of the elevation data collected for this research are dependent upon establishing a benchmark elevation. This benchmark must be a consistent reference for vegetation surveying and allow calibration to existing digital elevation models of the region. Tidal charts reference a zero elevation so they are applicable as a reference point for tide and elevation dependent vegetation in the marsh and they can be calibrated to various data sources, including satellite data and LiDAR imagery. These charts indicate the elevation of sea level at any time for a given region (Fig 8). The closest tidal gauge to the Los Cerritos Wetlands and the Alamitos Bay opening that feeds Steamshovel Slough is located at the Inner Island in the Port of Long Beach CA (Fig 9).

At any time during a low tide, it is possible to place markers in the mud flat along the water line and have a reference point for elevation by referencing the time of

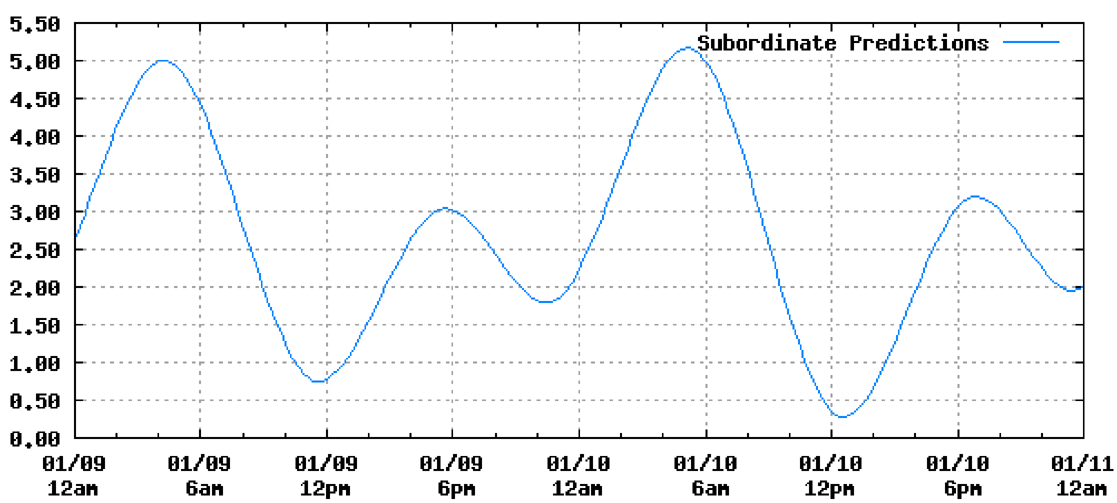

FIGURE 8. Similar NOAA tide charts were utilized to establish an elevation during vegetation sampling.

FIGURE 9. The map shows the proximity of the closest tidal gauge to Steamshovel Slough.

marker placement and the tide elevation that corresponds to that time. It is necessary to trace elevation during a low tide because high tides cover vegetation and make it exceedingly difficult to trace the waterline. NOAA's 0 feet elevation matches the 0 foot elevation for the North American Vertical Datum (NAV88). The tide marker ID is 9410686. All elevation measurements taken in the marsh were made relative to 0 feet for this tide marker.

In order to support the use of the NOAA tide charts as reference tides for Steamshovel Slough, it was necessary to evaluate whether a time lag exists between the true tide elevation and the elevation of the tides in Steamshovel. The fluctuation of the tide flowing into Steamshovel was thought to lag behind the time indicated by the NOAA tide charts due to the muting effect of the water flowing into an artificial bay opening. To align the determination of tide height in Steamshovel with the NOAA tide charts for Long Beach, the length of time delay had to be determined. The difference between the NOAA tide chart low tide and the actual time that the tide reached the full low tide extent was determined in the field by evaluating the actual tide levels and comparing them with the NOAA tides for the same period. To do this a marker was placed in the mud at the time of the lowest tide for that period. If the water level did not drop below the marker level then the NOAA tide chart could be used to accurately represent the tide height for Steamshovel, and no tidal delays would need to be accommodated. This evaluation was conducted during a low tide of 0.6 ft., on March 8th, 2014 at 10:24 AM. After the flags were placed no tide delays were recorded and, therefore, the NOAA tide chart was used as a reference tide in this research.

Surveying

Indicator Species

Due to the demonstrated difficulty in determining the fundamental factors that are responsible for the spatial distribution of marsh vegetation zones, and considering the observed adherence to elevation that these zones seem to exhibit, the elevation at which vegetation zones are most common best typifies the zonation of the salt marsh. Additionally, specific salt marsh species have been recorded as best representing these vegetation zones (Pennings and Callaway 1996; Zedler et al. 1994,1999; Noe and Zedler 2001a; Silvestri et al. 2005). This is the purpose for indicator species in the methodology for delineating elevation of vegetation zones.

Elevation Surveys

A Nikon Forestry Pro surveying tool and a reeling tape measure was used to obtain in-situ plant elevations measurements. All of the values derived from this data are in English units because tide charts for the area and the digital elevation map pixels are in feet. The values determined with these devices are variables in the following sine trigonometry equation.

EQ. 1

$$\text{Sin } (X^{o}) * \text{Hypotenuse} = \text{Opposite}$$

Sin (X^{o}) equals level of inclination, hypotenuse is the distance from viewfinder to the target and opposite is the vertical separation (the value that informs elevation change between two locations). Working the sine equation results in a height above the target. After O is determined, it can be subtracted from the height of the viewfinder at eye level of the user, leaving the elevation of the target above or below the location where the user was standing. The Nikon Forestry Pro is a monocular surveying tool. It is used only to determine the angle of inclination. The inclination is accurate to within a tenth of a degree. Inclination is the sine angle in the trigonometry equation. An average of five inclination measurements was used to determine this angle while in the field. The application of an analog measurement to determine H was preferred over using the Nikon for distance because of the Nikon's relatively course distance-to-target resolution. A reeling tape measure was used to determine the distance between the viewfinder and the target object. By holding the tape at the height of the user's eye and stretching it tight to the viewfinder target location, it is possible to determine the hypotenuse length. The target variable of the sine equation is the height difference between the range finder, held at eye height, and the targeted indicator species. Adding this height to the elevation above sea level gives an elevation above zero for the vegetation zone (Fig 10).

Determining Low Marsh Elevation

The minimum range of the low marsh indicator species was determined by standing at a marker for sea level while using the Forestry Pro to obtain the inclination of the angle to the edge of the low marsh (Fig 11). This edge of the low marsh location it is clearly distinguishable in the field because the contrast from mud flats to *Spartina foliosa* (Pacific Cordgrass) is plainly obvious. Cristina Robinson held the tape measure at the ground directly beside the first indication of *Spartina foliosa* (Pacific Cordgrass), while I, standing at a sea level marker based on the aforementioned tidal datum, recorded the tape measure distance and angle of inclination for the first point. The elevation of this first measurement served as a reference point for subsequent elevation measurements along the low marsh. We traced the lowest occurrences of *Spartina foliosa* (Pacific Cordgrass) in both directions away from the first measurement that referenced sea level. After tracing the low elevation range of the indicator species the measurements were moved to an area that was deemed as the demarcation of the highest elevation of monopytic stands of *Spartina foliosa* (Pacific Cordgrass). Elevation surveys for the upper limit of the *Spartina foliosa* paralleled the locations where lower limits were taken. Elevation readings frequently stretched to a distance of around 50 feet in both directions from the elevation reference point. This measurement procedure traced the perimeter of the low marsh zone for about 100 feet on three occasions and between 60 and 100 feet on three other occasions (Fig 10). Between 12 and 15 elevation samples were taken from each perimeter. The amount of elevation samples were dependent on visibility though the section of the marsh. The perimeters and the amount of elevation samples obtained were dependent on visibility throughout that section of the marsh.

Determining Marsh Plain Elevation

The marsh plain is constrained by the maximum extent of low marsh and the minimum extent of the high marsh. The determination of the minimum and maximum elevation for the marsh plain are based on the terminal and starting points of the low marsh and marsh plain respectively, as seen in Figures 11 and 12. Surveying a specific indicator species for this zone was unnecessary. The lowest elevation of the marsh plain was identified as the location with the lowest occurrence of any other species in monotypic stands. The only species not considered part of an assemblage was *Cascutta salina*,(Salt Marsh Dodder) because it is a parasitic plant species and does not adhere to ecological factors such as edaphic chemical composition, inundation or salinity, because it extracts nutrients from a host. The lowest elevation of the *Arthrocnemum subterminale* (Parrish's Glasswort) marked the terminal point of the marsh plain and the beginning of the high marsh.

Determining High Marsh Elevation

Determining the elevation for the high marsh began at the highest elevation of the low marsh, where the monotypic stands of *Spartina foliosa* (Pacific Cordgrass) transitioned to species assemblages. Collecting the vertical elevation change across the large flat marsh plain was determined with a similar methodology as previously described. Rather than attempting to aim the Nikon at the first occurrence of the indicator species while standing at the high extent of the low marsh, which frequently measured over 300 feet away, a series of smaller elevation surveys were used. Elevation

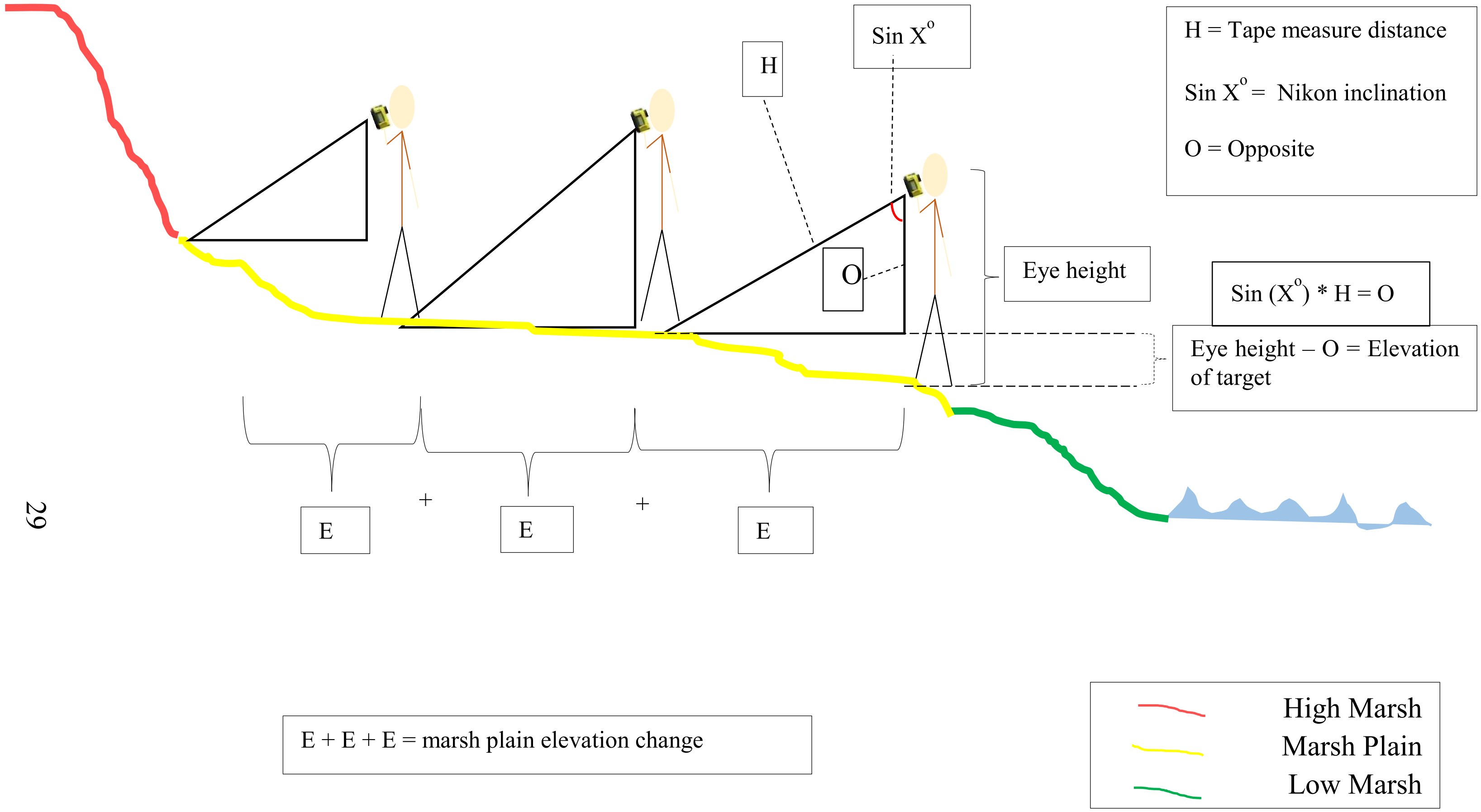

FIGURE 10. The illustration helps visualize the elements of the sine equation used in elevation measurements. The animated researcher aims the Nikon at the ground to determine elevation change. All of the elements in the sine equation are illustrated beside the researcher on the far right. The chain of elevation measurements, marked as E, determines the overall elevation change along the marsh, with the elevation measurement on the far left targeting an indicator species.

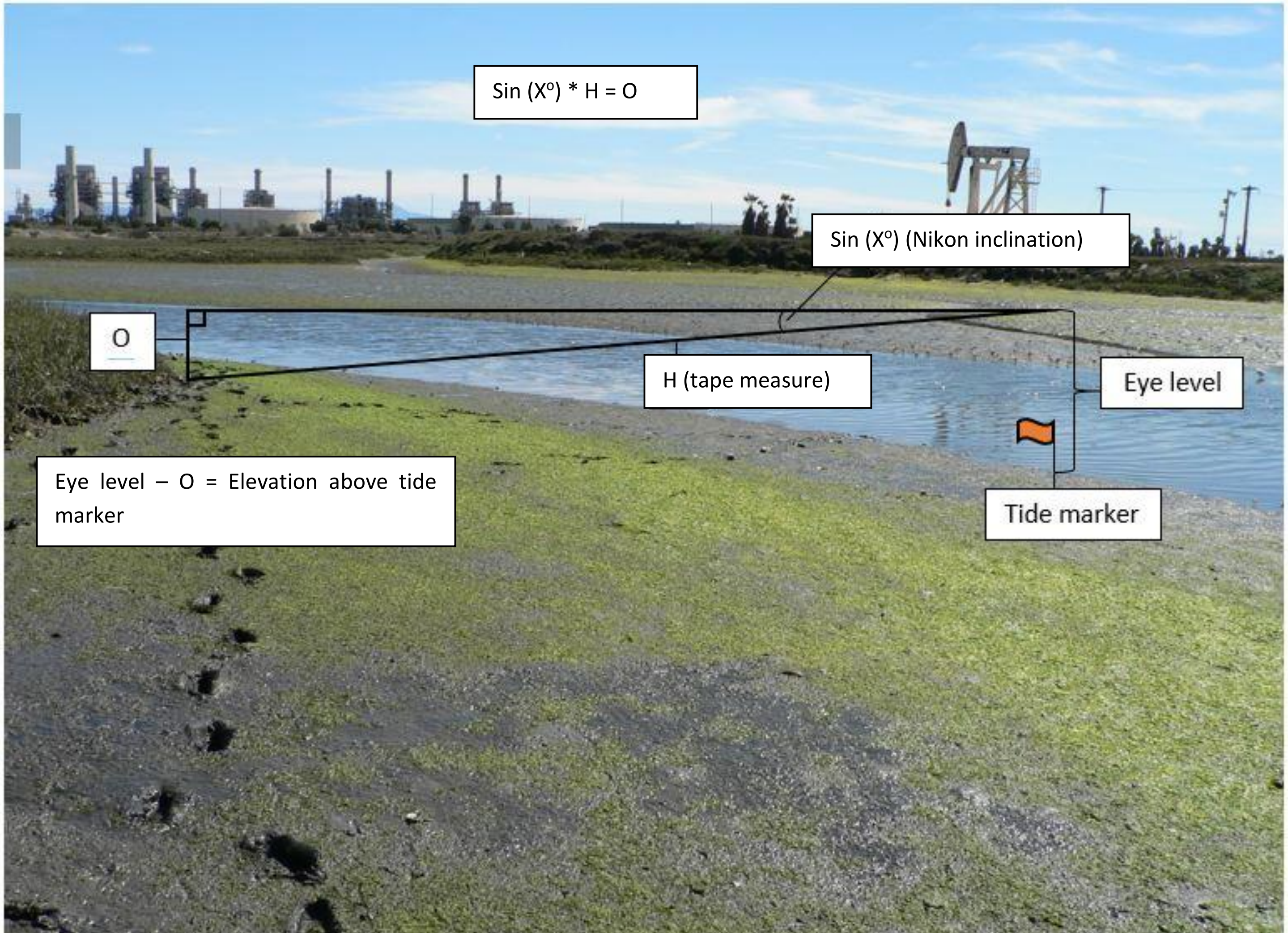

FIGURE 11. This illustration provides a reference for the elements of the trigonometry equation at a location where a survey was performed.

FIGURE 12. 1) The low marsh elevation is determined here after referencing the location of the sea level. 2). Elevation surveys begin at the upper extent of the high marsh and are used to determine the elevation change throughout the marsh plain. 3) Continuing from the first occurrence of the marsh plain, several elevation points are collected to determine the high marsh extent.

change surveys started at the upper elevation of the low marsh and continued to the location of the first occurrence of the high marsh indicator species. Summing the result of each of these surveys revealed an elevation change across the plain. The Nikon was pointed at the soil beside the feet of an assistant to obtain inclination. Again, the average of the angles the Nikon produced was used as the sine angle in the trigonometry equation. The length was determined by using a light fabric tape measure stretched tight and held at eye level to obtain the hypotenuse value. Subtracting the user's height at eye level from the opposite value produced the difference in elevation. The measurement process was repeated with each subsequent measurement beginning at the end-point of the prior survey. By adding the consecutive measurements together, a total elevation change from low marsh to an area near the high marsh could be determined. The total elevation change throughout the marsh plain plus the height of the upper limit of the low marsh establishes a reference elevation for measurements of the high marsh above sea level. It was essential to ensure that sampling was conducted in a non-destructive manner. Therefore care was taken to record measurements on locations where there was a bare patch of earth, thus avoiding potential trampling of native vegetation. As a result, the distance between survey points is not consistent. Although bare patches would have to be sought out, it was possible to find them along the profile path and a change of direction was not necessary.

Several different *Arthrocnmemum subterminale* elevations were recorded at the final location of the chain of surveys. The previously described methodology for determining elevation revealed the elevation of multiple plants. The plants targeted represent the individuals in the highest and lowest elevation observable.

In areas where the base of a target plant was not visible, a slightly different approach with the Nikon was used. An assistant stood at the location of the indicator species holding a tape measure at the ground directly beside the plant. The inclination is the angle of the Nikon when pointed directly at a specific height on the tape measure. Subtracting that measurement from the resolved elevation for that point results in a final elevation of the plant. This methodology is especially useful when identifying plant elevations at the upper end of the high marsh because the view could be obscured by growth.

<u>Testing the Accuracy of the Nikon and Tape Measure Method</u>

The Nikon Forestry Pro has certain inherent hurdles to overcome when used for elevation surveying of salt marsh vegetation. While operating the Nikon it was occasionally difficult to aim it very accurately, especially from larger distances. A control test was devised to determine the accuracy of the Nikon and Tape-measure method while in the field.

In order to test the accuracy of the Nikon, control variables in the sine equation needed to be determined. As previously discussed, the opposite value in the Sin equation is the height of the user's eye. The hypotenuse in the sine equation is simply determined by the distance along the tape measure; because this is measurement is controlled by the researchers we chose an H value that represented a distance that was frequently encountered in the field. The sine equation was back calculated with the eye height and hypotenuse values to obtain Sin (X^o) value. The equation used to back-calculate the sine equation is the Inverse sine equation.

Eq 2.

$$X = \mathrm{Sin}^{-1}\ (O/H)$$

The Inverse sine equation with O equaling the researcher's eye height, and with a hypotenuse of 540 inches results in an inclination of 6.75^o.

Eq 3.

$$\mathrm{Sin}\ (x) = 63.5/540$$
$$x = \mathrm{Sin}^{-1}\ (.1176)$$
$$x = 6.75$$

This result shows that at the researcher's eye height and at a distance of 540 inches along a level surface, a viewfinder inclination of 6.75^o should be expected.

The accuracy of the methodology can therefore be verified by aiming the Nikon directly at the ground along a hypotenuse of 540," recording the inclination, and cross checking the result. This test was set up in the wetland using the tape measure to determine the hypotenuse and two flags to mark survey locations. One flag represented the target and the other marked the location the researcher was to stand. A complication in the accuracy test was the possibility that an elevation difference existed between these two locations. If the ground elevation changes along the 540" hypotenuse, the result would not be accurate. In an attempt to verify that the test area is horizontal, this test was repeated in both directions along the same survey area. Two different users tested the accuracy of the method through eight separate inclination measurements in both directions. Accuracies are presented in the following chapter. The methodology proved robust enough to continue surveying methodology.

Scenario Choice

The scenarios used in this research to model the varying degrees of SLR are those that are most commonly found in recent literature. The IPCC's most recent assessment offers a hypothetical scenario list to predict the range of possible SLR. NOAA has also put forth SLR predictions. The complete range of SLR throughout all of the NOAA scenarios predicts sea level heights below the IPCC minimum and above the IPCC maximum. They range from 0.2 m to 2 m. Focus was then placed on SLR predictions along NOAA's predictions of between .7 ft and 6.6 ft. During the SLR analysis it became apparent extensive SLR may have the same ubiquitous impacts as that of moderate SLR scenarios, and, therefore, the upper end estimates were abandoned. For example, the upper end scenarios of four, five and six feet of SLR would correspond with a complete inundation of vegetation zones and the complete occupancy of mud flat and sub-tidal habitats in the marsh, rendering vegetation analysis useless; subsequently, attention focused strictly on scenarios that revealed changing habitat zones. These scenarios correspond with the low and median degrees of SLR, which are also the most likely SLR scenarios posited by both the IPCC and NOAA (Parris et al. 2012; Church 2013). Scenarios of one, two and three feet SLR were therefore used as values in the SLR scenario analysis.

Analyzing Vegetation Zones Using Geographic Information Systems

ArcGIS 10.1 was used to represent and visualize potential sea level rise in Stamshovel Slough. The base dataset was obtained from the CSULB Department of Geography license to the Los Angeles Region Imagery Acquisition Cosortium (LAR-IAC) digital elevation model (DEM) that was derived using Light Detection and Ranging (LiDAR) technology (LARIAC 2006). The DEM data were obtained from the NOAA Coastal Service Center (http://www.csc.noaa.gov/dataviewer/#, February 25 2014). The data were collected during the LARIAC data collection projects in 2006. These data have a vertical resolution of 2 feet, a horizontal resolution of 3.3 feet)

Six-inch contour intervals were rendered from the LARIAC DEM using ArcGIS Spatial Analyst. These intervals clearly illustrated the topography of the marsh. Because the LARIAC contour interval was greater than six inches, the interpolation of six-inch contour intervals is a false precision. These intervals define the locations of increased slope angle in the marsh. The elevation ranges defined by vegetation zone surveying informed a reclassification of the DEM values so that each class was associated with the elevation range of a specific zone. For example, every DEM elevation value that corresponded to the elevation range of the mud flat, which was between 0 and 17 inches, was reclassified as 1 and named mud flat. All of the vegetation zones were modelled for the elevation ranges of modern vegetation zones and named accordingly.

To model the rise of sea level, the elevation ranges needed to be reclassified. The assumption was made that if sea level were to raise one foot, all of the vegetation zones, being intimately tied to elevation above sea level, would also move up in elevation by one foot. Elevation values in the DEM were reclassified to model degrees of SLR. For example, under a SLR scenario of 3 feet, DEM values below 3 feet were classified as 0 to represent the location of sea level. The low marsh, which grows between 17 inches and 30 inches, was mapped as growing 3 feet higher than the surveyed height, 53 inches and 66 inches, respectively. This process was repeated for each vegetation zone and its elevation after one, two and three feet of SLR. ArcGIS was used to generate topographic profiles using 3D Analyst. The data for the profiles from the DEM were exported as HTML documents from ArcGIS into OpenOffice Calc 3.1, where the surveying results were used to inform the grouping of points along the elevation profile to represent vegetation zones.

The Challenge of Navigating the Salt Marsh

For those yet unfamiliar with the navigability of a tidally influenced coastal salt marsh, the difficulty in collecting data may come as a surprise. The coastal salt marsh mud flat is a trap for any boot that steps in the wrong location. It is quite possible to sink immediately to a depth of twelve inches or more. Once embedded into the mud, it is exceedingly difficult to remove a foot (or leg) without losing a shoe, sock, or boot; additionally, the challenge of standing on this surface complicated the collection of vertical measurements. In most instances, a pace in either direction was enough to find soil that was sturdy enough to take the quick measurements necessary to establish a reference point. A reference point was not be used if it was impossible to make a measurement from regular eye level. The mudflats did have locations, often visually discernable by a layer of algae and darker soil conditions, that were solid enough to support weight while measurements were being taken. This challenge was only of significance when gathering elevation for the reference point relative to the tide marker. Elevation measurements close to vegetation were typically established from far more solid terrain that could be stood on with little problem, other than it being very slippery.

The eastern quarter of the salt marsh along Studebaker Road, between the mud flats and approximately the middle of the marsh plain, proved exceedingly difficult to navigate. This expansive section of marsh plain measured over 1000 feet from the low marsh to the high marsh. Here, the high marsh indicator species were rare, and poorly represented the vegetation zone, possibly because of a dense mixture of concrete slabs and small segments of discarded brick wall. At the low marsh zone, the assemblage of species spread to the mud flats. Monotypic stands of *Spartina foliosa* were more difficult to locate due to the size of the area being surveyed and the overall trouble encountered with navigating this terrain. This area of the marsh also represented the area with the most gradual and consistent topographic relief. We avoided sampling elevation in this region because of difficulty in obtaining reliable elevation data, as well as the absence of defined zonation in the marsh here.

CHAPTER 4

RESULTS

Surveying Results

The elevations of vegetation zones in Steamshovel Slough ranged from 0-87 inches (TABLE 1). The results of the in-situ elevation surveying of indicator species are presented below along with a series of maps showing the modelled vegetation ranges after one, two, and three feet of SLR. The elevations reference the zero elevation from the Long Beach, Inner Harbor station, ID: 9410686. Elevation profiles extracted from the LiDAR DEM assist in the visualization of vegetation zone migration. The profiles also help reveal universal aspects of the topography in Steamshovel Slough. Specific topographic features of the marsh are referred to with repetition, as such, a brief introduction to the terminology is necessary.

Steamshovel has two distinct locations where the topography has an abrupt incline followed by a transition back to nearly horizontal, referred to as an "abrupt topographic rise." One abrupt topographic rise is at the location where mud flat becomes

TABLE 1. Vegetation Zone Elevations

Zone	Elevation (inches)
Mudflat	0-17
Low Marsh	17-30
Marsh Plain	30-44
High Marsh	44-87

the low marsh. This area is referred to as the “bayward edge” of the marsh. Another feature commonly referred to is the “artificial elevation gradient” that marks the terminal point of the marsh. This feature runs the length of the marsh and is relatively straight because the raised topography was built to confine the straight Cerritos channel. These features are seen throughout the marsh and are distinguishable in nearly every location but with varying degrees (Fig 13).

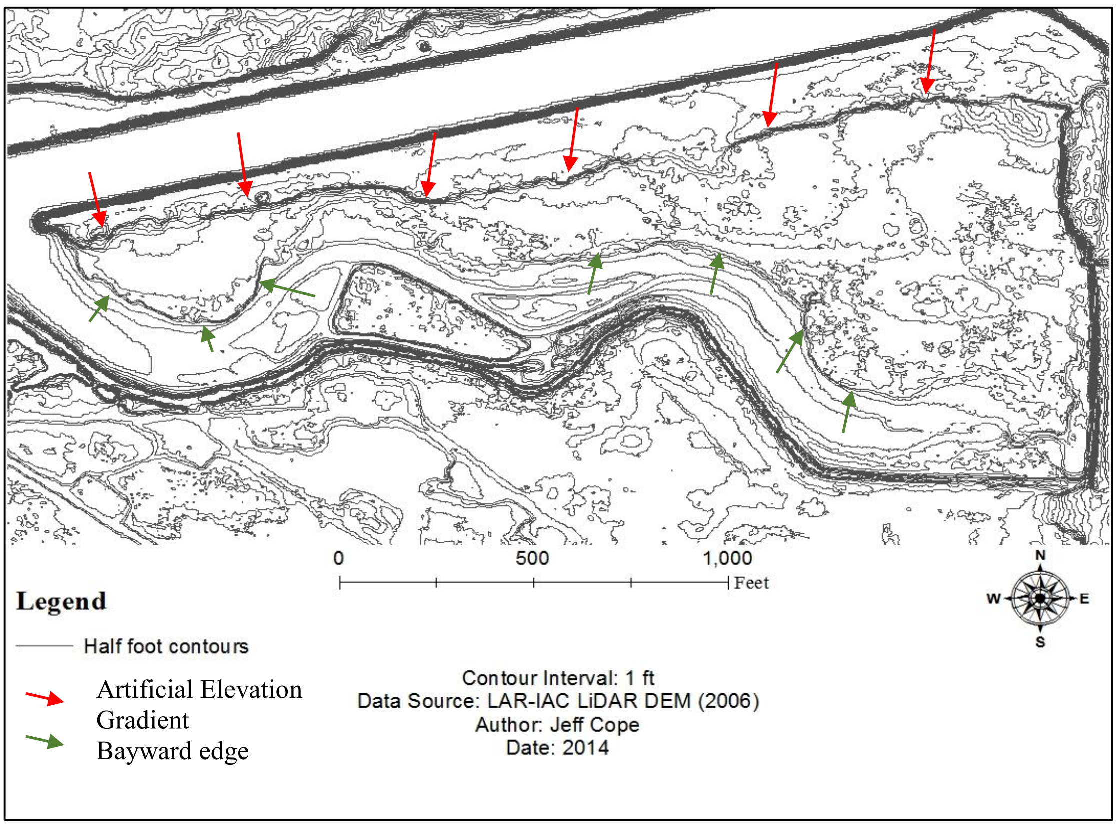

FIGURE 13. The contour map shows the topographic features in the marsh that are common, and have a distinct impact on the vegetation zones.

Vegetation Zone Area Results

Figures 14, 20, 22 and 23 depict the vegetation zone surveying results, visualized through reclassification of the LARIAC LiDAR DEM. In ArcGIS, polygons containing all the elevation values for a specific vegetation zone were rendered, as well as polygons for sea level and mud flats. Descriptions of the visible changes between the current vegetation zone locations and the modeled zone locations move roughly from west to east, beginning with the low zones, and moving to high zones.

Modern Vegetation Zones

The vegetation zones shown here represent the current state of the marsh (Fig 14). Throughout the marsh, the low marsh exists in a narrow band along the abrupt elevation incline at the bayward edge of the marsh. About one third of the way from the western extent of Steamshovel, at the location where the water meanders north towards the artificial elevation gradient, *Spartina foliosa* habitat spreads out. This area also corresponds to a change in topographic profile. The low marsh does not exhibit any sudden elevation rise but instead has a rather consistent slope. The low marsh zone of 17 to 30 inches above sea level covers an area over 175 feet, a slope of 0.6%. East of this area, the habitat for the low marsh reverts to the thin band associated with the abrupt elevation rise at the bayward edge of the marsh vegetation. At the farthest east extent of the marsh, low marsh habitat expands again at another location of reduced gradient. The low marsh habitat extends into a riverine system that delivers a tidal influence to the eastern section of the expansive marsh plain. Upon the rendering of these vegetation

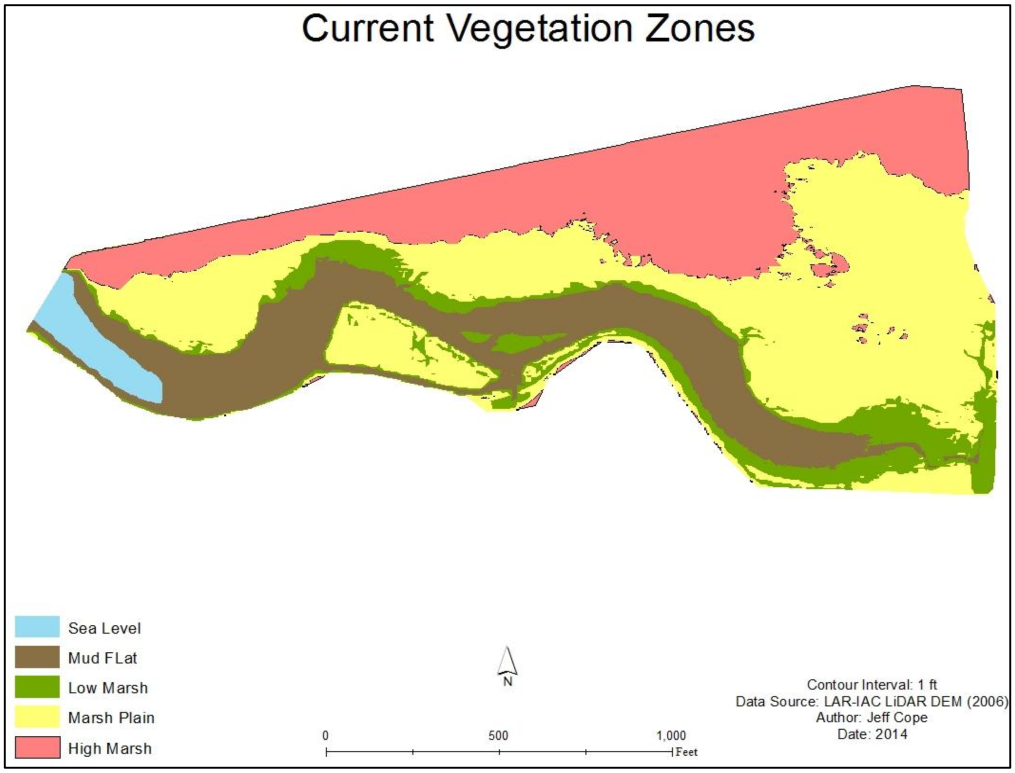

FIGURE 14. This map represents the current state of the marsh with vegetation zones reflecting in-situ vegetation surveying.

zones, the location of *Spartina foliosa* along this section of marsh was verified in the field (Figs 15 & 16). The low marsh zone has intrusions of the low marsh into the marsh plain corresponding with locations of topographic heterogeneity in the marsh. *Spartina foliosa* stands in areas of topographic heterogeneity were associated with above average elevation for the species (Fig 17). Areas of topographic heterogeneity did not exhibit the overall elevation trend of the low marsh and represent a disproportionately small overall area of the low marsh habitat; thus, elevations there were not included in consideration of the upper limit of the habitat range. Today, the marsh plain exists entirely between the

FIGURE 15. This photograph is from the riverine system that runs along the eastern extent of Steamshovel. It shows *Spartina foliosa* stands thriving along the banks.

FIGURE 16. *Spartina foliosa* stands are slightly more difficult to see here. They line this inlet/outlet system for over 300 feet.

two areas of steep elevation gradient at the bayward edge and terminal point of the marsh zones. The marsh plain only deviates from its confinement by these features in areas where the elevation gradient is somewhat subdued. Surface features in these locations show signs of fluvial erosion, a possible source for the grading of the surface slope. In these locations the high marsh moves down into marsh plain areas. The high marsh zone adheres to the artificial elevation gradient along the entire marsh with two exceptions. Two distinct areas, where the artificial elevation gradients break down, mark locations where *Arthrocnemum subterminale* has moved spread laterally away from the artificial elevation gradient (Fig 18). A very slight levelling of the artificial elevation gradient exists in the far western section of the marsh; it is associated with *Arthrocnemum subterminale* in that location. Another much more prominent smoothing of the artificial elevation gradient occurs in the central/eastern extent of the marsh, as seen where the high marsh zone moves out significantly into the marsh plain. Again, a simple ground truth revealed this location to contain *Arthrocnemum subterminale*. Figure 10 revealed the occupancy of the indicator species in this location. Finally, an island of high marsh is shown isolated in the expanse of the marsh plain in the eastern extent of the marsh. The presence of *Arthrocnemum subterminale* needed to be verified here as well (Fig 19). The vegetation zone exists here on a slight topographic rise, in the middle of the marsh plain. Total area for each vegetation zone and the area and percent change are shown in TABLE 2.

FIGURE 17. Areas of elevated vegetation zones are visible along the interface of low marsh and mud flat.

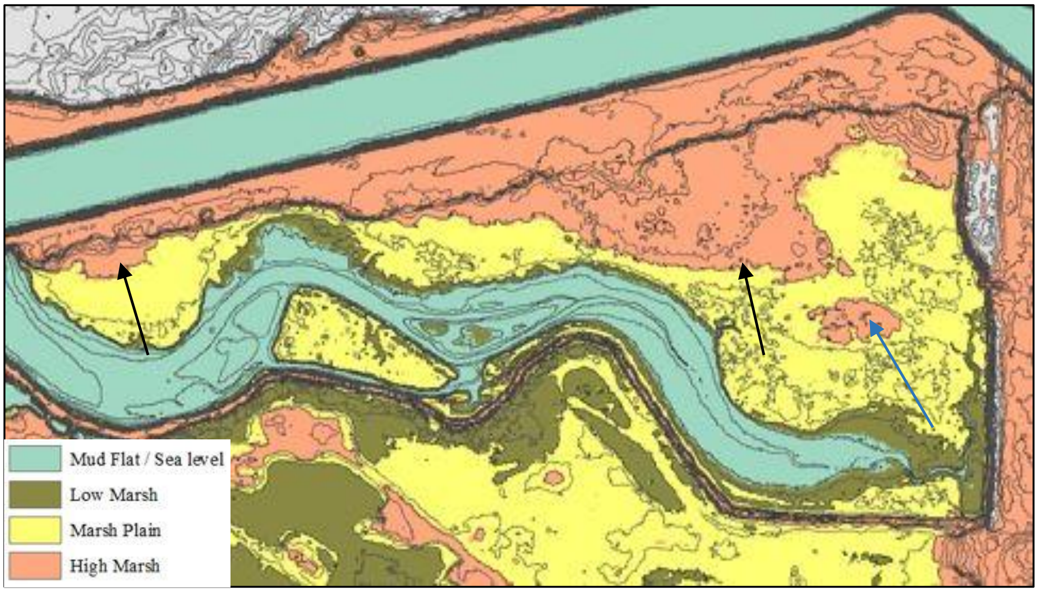

FIGURE 18. The black arrows indicate the two locations where the elevation gradient breaks down and *Arthrocenmum subterminale* reaches into the marsh plain. The blue arrow indicates the location of the island of *Arthrocenmum subterminale* on the topographic rise, ground truthing here reveals a strict adherence of the species to elevation.

FIGURE 19. At the topographic rise in the eastern marsh plain, the indicator species appear as darker green vegetation. This is the only section of elevated topography in this section of the marsh and was easily identified in the field.

TABLE 2. Vegetation Zone Changes in Los Cerritos Wetland

Vegetation Zones	Area (Ft^2)		
High Marsh	469666		
Low Marsh	176296		
Marsh Plain	658534		
Mud Flat	316817		
Sea Level	38067		
Vegetation Zones, 1 ft SLR		Area Change from Current	Percent of Current
High Marsh	323408	-146258	68.9
Low Marsh	570856	394560	323.8
Marsh Plain	250414	-408120	38
Mud Flat	292392	24425	92
Sea Level	223116	185049	586
Vegetation Zones, 2 ft SLR			
High Marsh	290170	-179496	61.8
Low Marsh	254223	77926	144.2
Marsh Plain	57134	-601400	8.7
Mud Flat	602317	285499	190
Sea Level	456657	418589	1200
Vegetation Zones, 3 ft SLR			
High Marsh	122601	-347065	26.1
Low Marsh	55049	-121247	31.2
Marsh Plain	178841	-479693	27.2
Mud Flat	518734	201917	164
Sea Level	785434	747367	2063

Note: All values show the change and percent remaining are relative to current values.

Vegetation Zones for One Foot of SLR

A dramatic shift in vegetation zone area appears with the modelling of a one-foot SLR scenario (Fig 20). Sea level and mud flat move slightly higher in elevation along the periphery of the entire marsh but it is most noticeable near the eastern arm of the marsh and especially along the stream cut channels in the far eastern side of the marsh. The starkest contrast to this scenario is the presence of low marsh throughout the plains of the marsh. The low marsh is predicted to dominate the surface area of Steamshovel Slough after a SLR of just one foot. Throughout the marsh, low marsh will push back the boundaries of the marsh plain to beyond the current location of the high marsh.

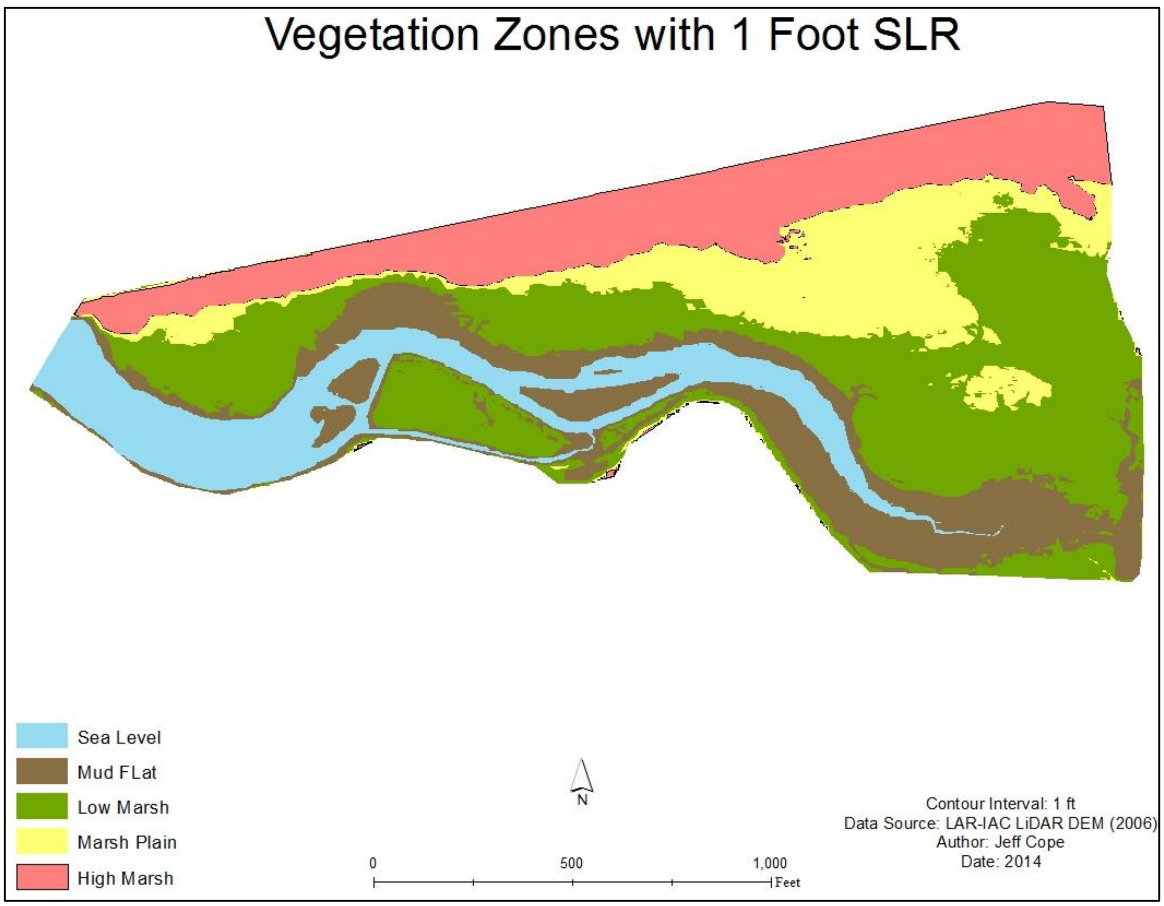

FIGURE 20. Expected vegetation zones after one foot of SLR. The largest change visible is the advance of low marsh into the marsh plain. The low marsh expands by 323.8%.

This is among the most dramatic surface type changes expected for the marsh for any SLR scenario. The small island of vegetation that exists in the central/western portion of the marsh, just north of the southern boundary, will also convert from marsh plain to low marsh. Low marsh claims the majority of the expansive eastern arm of the marsh. The large high marsh area associated with the reduced elevation gradient in the eastern arm of the marsh will transfer to the marsh plain, along with the small island in the center of the eastern plain. In this scenario, the high marsh yields almost entirely to the upland migration of marsh plain, except for one area in the upper elevation of the section of a more consistent elevation gradient in the central/eastern plains of the marsh (Fig 21). Hypothetically, the high marsh possesses the large upper elevation areas of the marsh north of the artificial elevation gradient; but, as of today, the area here is not vegetated despite close proximity and no elevation separation between areas of vegetated high

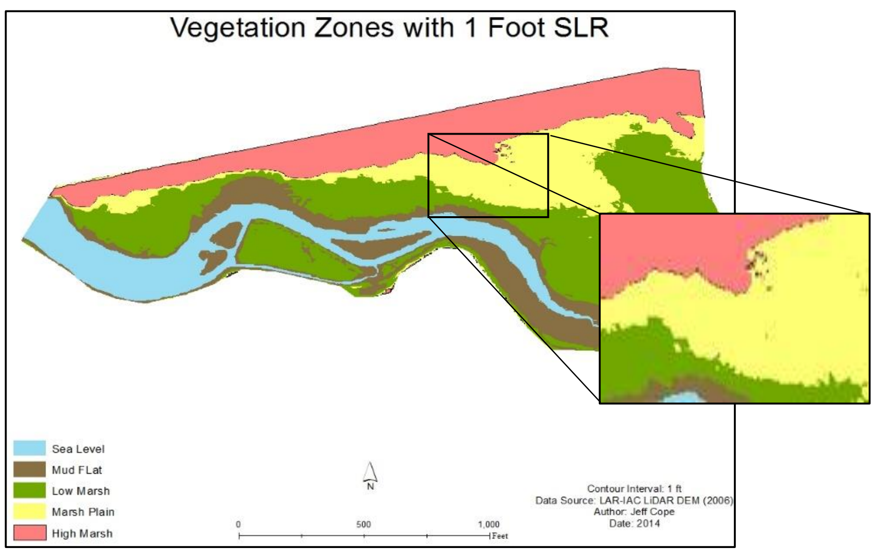

FIGURE 21. The location with a consistent elevation gradient in the central/eastern area of the marsh allows high marsh to jut out into the marsh plain

marsh. It is conceivable that the soil here, which consists of fill material to add elevation to the confining walls of the Cerritos channel, may not be suitable for vegetation habitat.

Vegetation Zones for Two Feet of SLR

The two feet SLR scenario could completely change the ecology of Steamshovel Slough and it is a clear example of coastal squeeze (Fig 22). This scenario drives the tides and mud flats above the elevation of the steep elevation gradient at the current bayward side of the marsh and over the marsh plains that represent the vast majority of

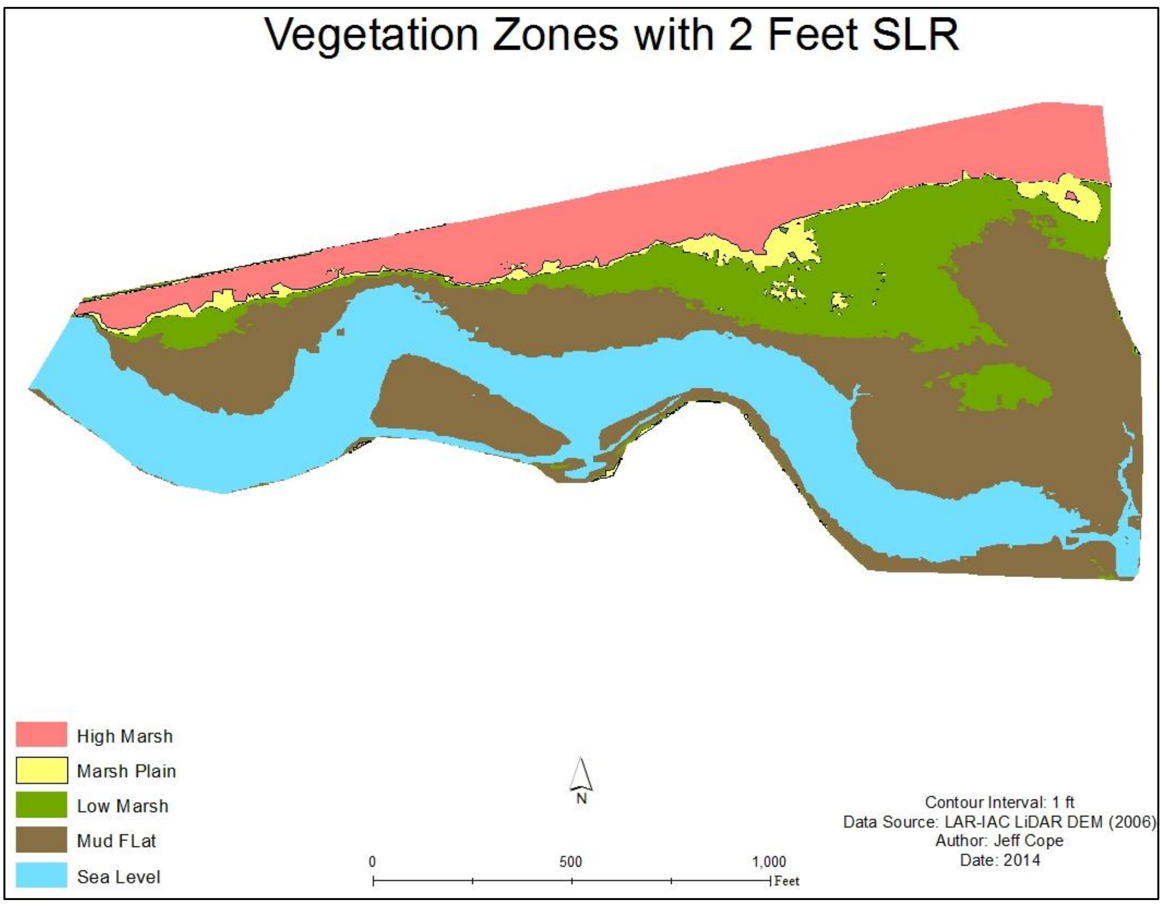

FIGURE 22. Two feet of SLR results in staggering losses to the marsh plain, which only represents 8.7% of the current area.

total surface area of the marsh. *Spartina foliosa* will have habitable elevation along the reduced artificial elevation gradient in the western extent of the marsh and possibly a thin band along the entire artificial elevation gradient of the marsh extent to the point of more reduced gradient in the central/eastern portion of the marsh. It may also possess area around the small topographic island in the center of the eastern plain. In this map, the low marsh perfectly outlines the area that composes the "reduced elevation gradient" portion of the marsh. The marsh plain has lost the battle against coastal squeeze in this scenario. It may only exist in one or two small pockets at the highest elevations around the reduced artificial elevation gradient near the eastern portion of the center third of the marsh. The high marsh shows little variation from the one-foot scenario except that it will lose habitat in the lower elevations around the reduced artificial elevation gradient in the central third of the marsh and also the smaller region of reduced artificial elevation gradient at the extreme western and eastern arm of the marsh. The marsh plain is sparsely scattered throughout the lowest elevations of the artificial elevation gradient.

<u>Vegetation Zones for Three Feet of SLR</u>

Under the three feet SLR scenario, the vegetated regions throughout almost all of Steamshovel Slough will suffer a transition to mud flat or to aquatic habitat (Fig 23). Low marsh possess a small area of habitat around the reduced artificial elevation gradient. In this hypothetical situation, the marsh plain will actually recover after sea level rises passes the two foot mark and forces the marsh plain up into the highest elevations of the marsh. The marsh plain expands into the highest reaches of

Steamshovel Slough and increases in overall area as the sea level a approaches 3 feet rise. Consequently, this scenario sees a dramatic decrease in the high marsh.

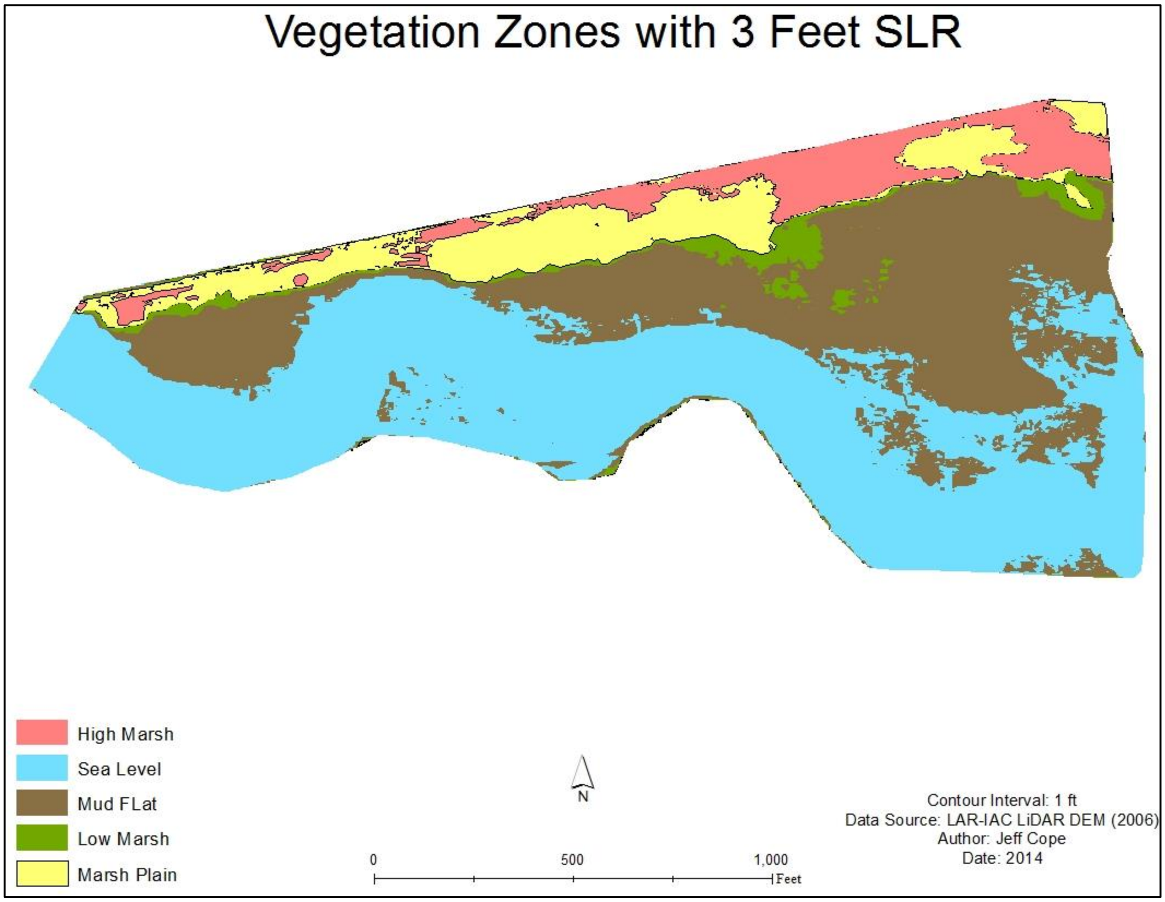

FIGURE 23. Many climate models consider the three-foot scenario likely; it is the only scenario resulting in a reduction to each of the vegetation zones. Each zone represents less than 32% of the current vegetation zone area.

Survey Accuracy Assessment

Seventy-five percent of the elevation measurements had better than half an inch vertical accuracy from 45 feet, the remaining 25% was accurate to 1.5 inches. The value tested was the overall height at eye level because that is the value sought in the field. Forty-five feet was chosen as a test distance because it was similar to the distances frequently encountered in the field. The Nikon/tape measure based methodology for determining the variables of the trigonometry equation possesses a strong utility to the research presented here and were used to derive all of the elevation data presented here.

Marsh Profiles

Topographic profiles were drawn across the research area. The topographic profiles in figures 24-27 reflect the elevation of vegetation zones and the expected changes when responding to three different SLR scenarios . While observing these profiles it is fundamental to recall the vegetation zones inseparable connection to elevation above sea level. A zone tied to elevation as closely as those of the coastal salt marsh is under strict control from the subtle fluctuations in topography. As sea level rises and these vegetation zones migrate inland to maintain a location relative to the tides. They move into or through sections of the marsh with varying elevation profiles. If the slope angle of future habitat of the marsh is minimal, it will result in a greater lateral area when the zone migrates. For example, if the elevation of a region ranges from 17 inches above sea level to 30 inches above sea level over 25 feet of marsh, the low marsh will be confined to this 25 feet. If the elevation of a region ranges from 17 inches above sea level to 30 inches above sea level throughout an area of 200 feet, the low marsh will occur throughout a much larger area. In this sense the topographic profile, in conjunction with the known vegetation zone elevations, determines the total habitable space for any given vegetation species.

The results of the elevation profile analysis are presented in the same order as surveyed in the field. The first series of maps shows the current vegetation area map with the topographic profile as well as all three scenarios of SLR. The profile displaying these zones most distinctly reflects the topography of the marsh, including the two pronounced topographic rises, the rise at the bayward or water edge, and the rise along the artificial elevation gradient. It is also one of the locations chosen for elevation surveying. It combines an area map with the topographic profiles. The profiles include the elevation of vegetation zones.

Following the area maps and profile discussion are six profiles and an approximate location for them throughout the marsh. Additionally, a one-foot SLR scenario is included for each of these transects to exemplify the commonality of the effects of SLR on each of the locations.

Current Vegetation Zones with Topographic Profile

The profile referred to throughout this portion of the discussion most accurately reflects the topographic features of the marsh that significantly affect the migration of Steamshovel Slough vegetation (Fig 24). A mud flat is a ubiquitous feature throughout the marsh, always found between the waterline and the lowest vegetation, which is usually *Spartina foliosa.* The species marks the beginning of the low marsh zone at elevations starting at 17 inches above sea level and extending to 30 inches above sea level, at the first appearance of another salt marsh species. The low marsh elevation zone is relatively distinct within a thin band. Quite frequently in Steamshovel Slough, the low marsh habitat coincides with the dramatic and abrupt rise in elevation. This results in a low marsh zone that occupies little space relative to the total space of the marsh.

At the upper extent of the low marsh, the monotypic stands transition to assemblages of several species. This assemblage is the marsh plain, which increases in diversity as one moves through the plain away from the water. The most common

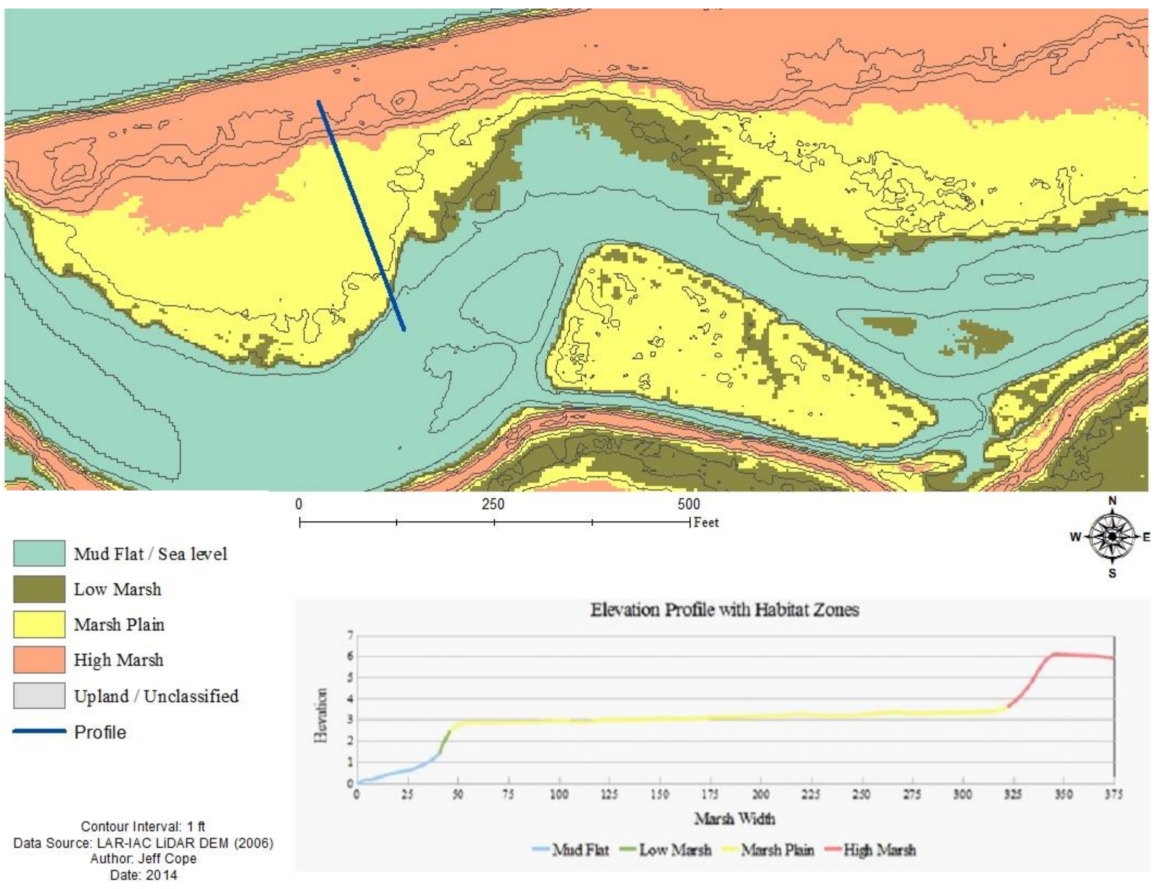

FIGURE 24. This map and elevation profile shows the locations that the vegetation zones occur on the topographic profile. The profile shown is just one of several locations surveyed.

species' found in the marsh plain are: *Spartina foliosa, Batis maritime, Jaumea carnosa, Salicornia pacifica, Sueda esteroa,, Triglochin concina, Distichlis spicata, Distichlis littoralis* and *Frenkenia salina* (Pacific Cord Grass, Saltwort, Fleshy Jaumea, Pacific Pickleweed, Estuary Sea-blite, Arrow Grass, Salt Grass, Shoregrass and Alkali Heath.) The marsh plain occupies a narrow swath in elevation between 30 and 44 inches. Although the elevation zone is rather short, this zone occupies a vast majority of Steamshovel Slough. The elevation profile flattens considerably throughout the marsh plain and may even decrease in elevation slightly as one moves away from the bayward side of the marsh. In fact, some areas the marsh plain occupies locations that are within the elevation range of *Spartina foliosa*, but, as Zedler et al. (1999) explain, *Spartina foliosa* does not occur away from the bayside of the marsh, except for locations of topographic heterogeneity extending into the marsh plain from along the mud flat/low marsh boundary. This is because the interior of the marsh plain lacks the tidal influence that the leading edge of the vegetation zone is subject to. The marsh plain comes to an abrupt end as the elevational profile increases in slope angle. This increase in the inclination of the topography is associated with the artificial elevation gradient, which contains the Cerritos Channel. It marks the northern extent of the entire salt marsh. At this point, the occurrence of *Arthrocnemum subterminale* marks the beginning of the final salt marsh zone, the high marsh.

The high marsh is an assemblage of few species, mostly salt marshes grasses like *Distichlis spicata* and *Distichlis littoralis* and the indicator species for the high marsh, *Arthrocnemum subterminale*. Throughout a vast majority of Steamshovel Slough, the high marsh can already be seen exhibiting signs of coastal squeeze, as previously indicated. The high marsh is confined to a slim area because of its location along a steep elevation gradient. This gradient rises from approximately 44 inches above sea level to a height of about 60 inches above sea level, with certain sections reaching 84 inches.

Modelled One Foot SLR Vegetation Zones with Topographic Profile

The future inland/upward migration of the habitat zones is plainly visible between the current vegetation zones and those projected for a SLR of one foot (Fig 25). Under the one-foot SLR scenario, the mud flat area is squeezed along this lowest section of the marsh. The low marsh stands to inherit the vast relatively flat section of the marsh once occupied by the marsh plain. At the top of the current low marsh, the topographic profile flattens from a steep angle to a relatively flat plateau. As the topographic relief flattens it does so directly within the one foot SLR elevation range of *Spartina foliosa.* In other words, *Spartina foliosa* habitat will exist at the elevation through which the marsh is the flattest if sea level were to rise just one foot. The upper limit of this species range will move from an area roughly 25 feet from the edge of the mud flat to an area that extends nearly 300 feet from the mud flat in some areas

The expansion of the low marsh corresponds with a significant decline in the habitat available in the marsh plain. As the marsh plain migrates away from rising tides, the lower limit of the zone moves from the steep elevation gradient through the elevation of the large flat plain and into an area of steep elevation gradient at the opposite side of the marsh resulting in a vast decrease in habitat space. Several species growing within it

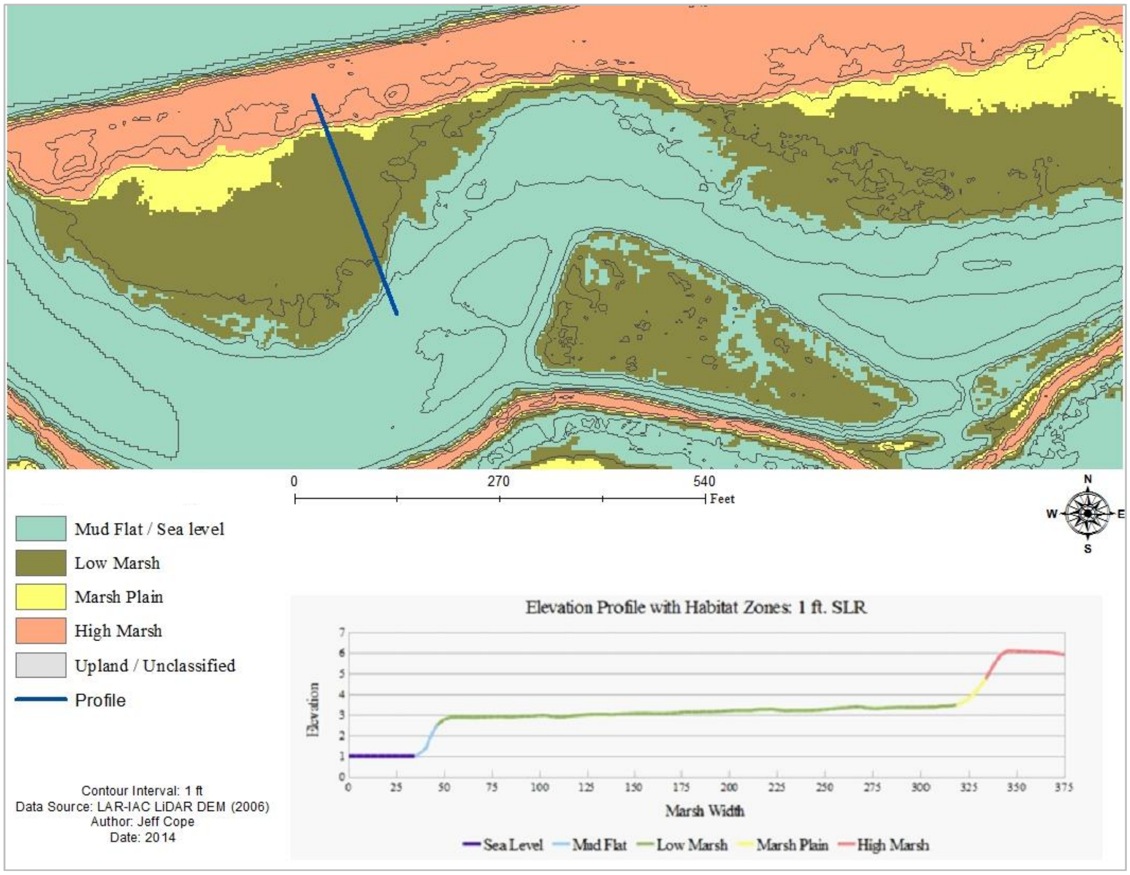

FIGURE 25. This profile, in the western arm, reflects the marsh topography with surveyed vegetation zones after responding to 1 foot of sea level rise.

will lose out substantially, a grim forecast for species like the endangered Belding's Savannah Sparrow. The Belding's Sevannah Sparrow nests solely in the leaves of *Salicornia pacifica,* (Common Pickleweed). A sea level rise of just one foot could leave the Belding's Sevannah Sparrow with no habitat in the Los Cerritos Wetlands. A one-foot SLR will squeeze the marsh plain to a habitat zone approximately 10 feet wide in most places, whereas today, in most sections of the marsh the marsh plain occupies areas of marsh more than 200 feet across. The habitat range of the high marsh is only slightly affected by a SLR of 1 foot. The high marsh can be expected to migrate up the steep artificial elevation gradient at the northern extent of the marsh, but it roughly maintains the overall area because the upper extent of the high marsh is only minimally influenced.

Modelled Two Feet SLR Vegetation Zones with Topographic Profile

Dramatic changes throughout the marsh become apparent with a two foot SLR scenario as well (Fig. 26). In this scenario, the vast extent of the m arsh topography is within a frequently inundated zone of tidal fluctuation. This scenario results in the coastal squeeze of every marsh zone against the artificial elevation gradient that limits the extent of the marsh. Nearly the entire large flat section of the marsh lies within the range of the mud flat. The low marsh habitat low range will migrate from the steeply sloping area in the first 50 feet of the marsh to the steep slope of the artificial elevation gradient along the marsh limit. The reduction in habitat area is similar to the effect of the one-foot scenario on the marsh plain. The marsh plain and the high marsh are both squeezed against the artificial elevation gradient along the extent of the marsh. This scenario of SLR will result in a vast disturbance of the ecology of the salt marsh. Two feet of SLR will add a substantial amount of aquatic and mud flat habitat. At this stage the coastal salt marsh habitat will be mostly lost. The only zone with the appropriate elevation to maintain a significant amount of habitat is the flat raised elevation along the top of the artificial elevation gradient that contains the Cerritos channel, the area where the elevation profile stops. The high marsh possesses the large upper elevation areas of the

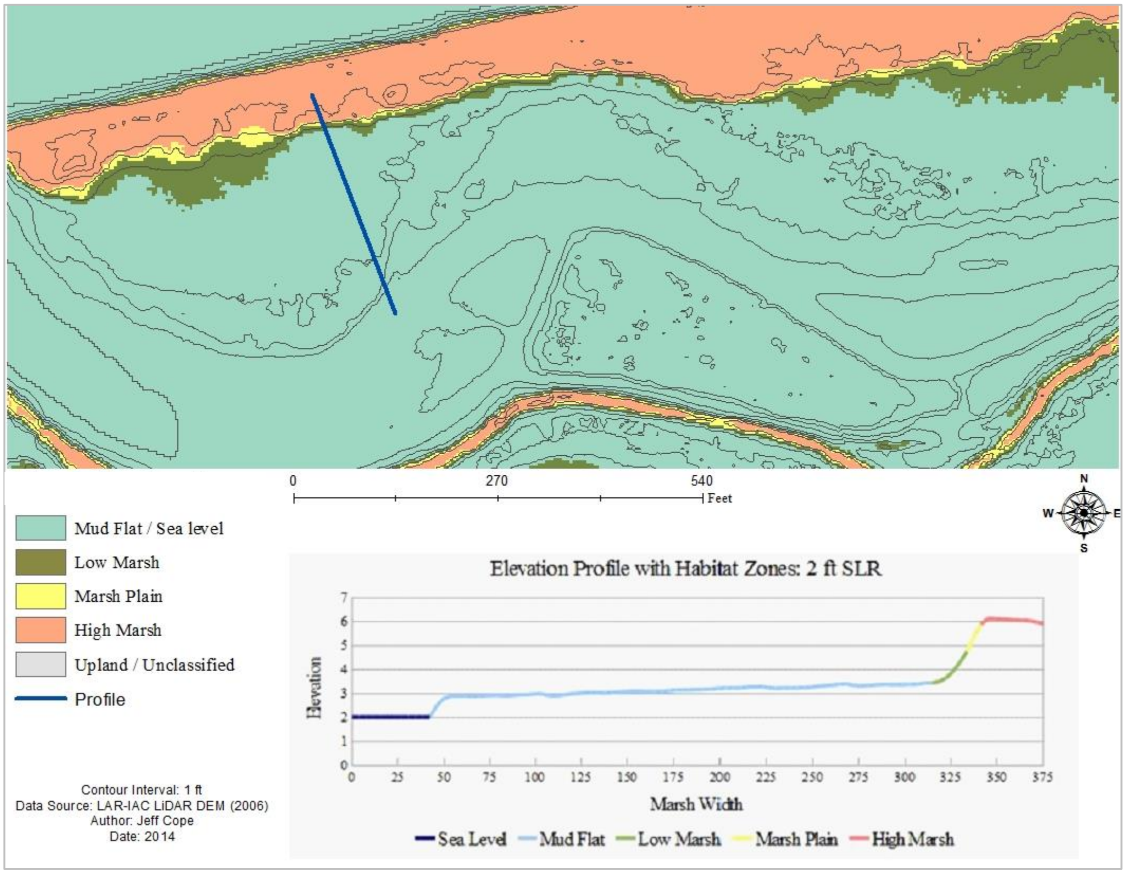

FIGURE 26. This profile, in the western arm, reflects the marsh topography with surveyed vegetation zones after responding to 2 foot of sea level rise

marsh north of the artificial elevation gradient; but, as of today, the area here is highly devoid of vegetation despite close proximity and no elevation difference between areas of vegetated high marsh. It is conceivable that the soil here, which is fill material to add elevation to the confining walls of the Cerritos channel, may not be suitable for vegetation habitat. While this scenario may be beneficial for the mollusks, bivalves and other mud dwelling creatures as well as any aquatic species, it will dramatically reduce terrestrial species habitat

Modelled Three Feet SLR Vegetation Zones with Topographic Profile

Three feet of sea level rise only adds a slight degree of coastal squeeze to Steamshovel Slough (Fig. 27). At three feet of SLR, mud flat still dominates most of the topography throughout the marsh. The large flat area comprising the current marsh plain will be entirely mud flat after 3 feet of SLR. The first appearance of the low marsh

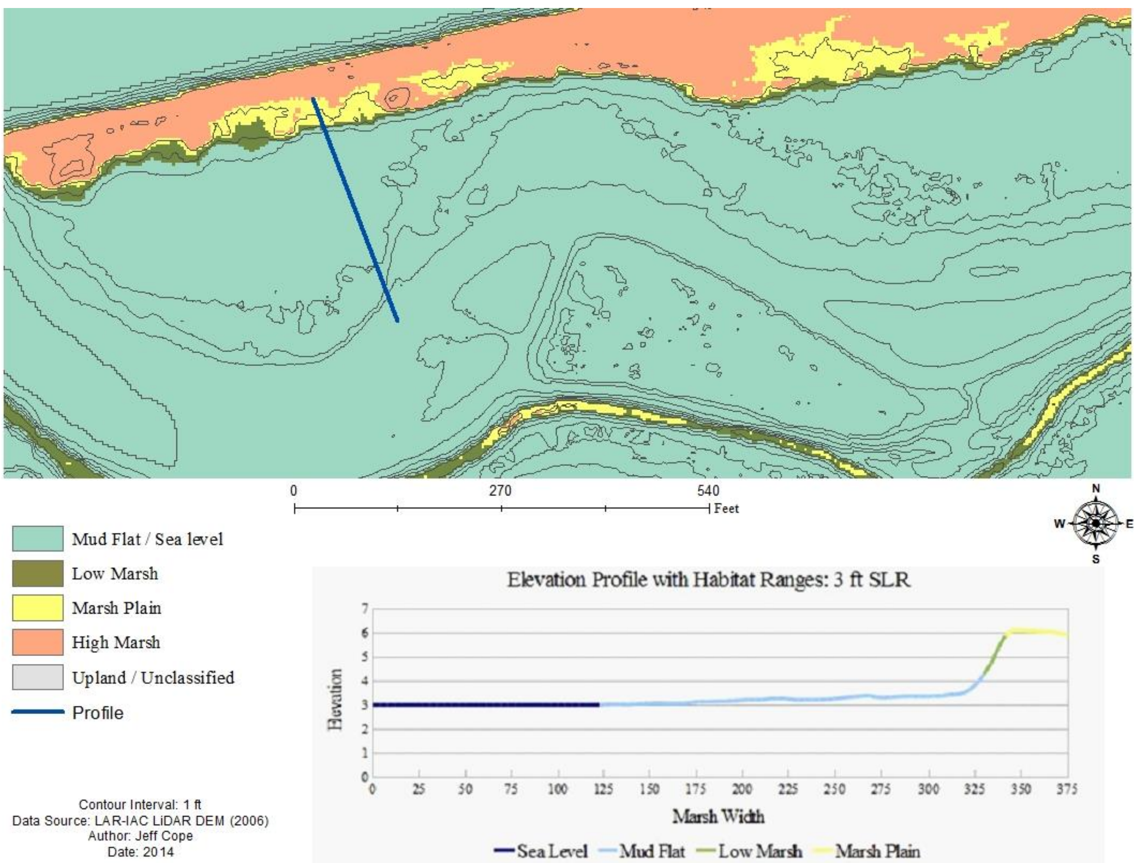

FIGURE 27. This profile, in the western arm, reflects the marsh topography with surveyed vegetation zones after responding to 3 foot of sea level rise

appears far up the artificial elevation gradient along the limit of the marsh. The low marsh and marsh plain occupy the habitat along the artificial elevation gradient as with the 2-foot scenario. The profile presented here is unique in that it only represents these two zones. In much of the marsh, the artificial elevation gradient rises to heights that are not suitable for the marsh plain, but, in this profile, the marsh plain is represented. Few areas will satisfy the elevation necessary for *Spartina foliosa* and the low marsh zone. This scenario will create a vast shallow protected aquatic habitat, a possible future habitat for any strictly aquatic species like the newly arrived Pacific Green Sea Turtles. Aquatic species may therefore benefit dramatically should sea level rise by two feet.

Marsh Profiles with Modelled One foot SLR

Elevation profiles along six of the twelve transects show the topographic variations of the marsh to inform this research to the vegetation zone migration (Fig 28). The intention for the elevation profiles here is strictly to show the topographic features of the marsh, emphasizing the similarities throughout the marsh. These profiles also illustrate vegetation zones with a one-foot SLR (Figs 29,30,31,32,33, and 34).

The x-axis represents the width of the marsh from sea level on the left to the highest reaches of the marsh on the right and the y-axis represents elevation in feet. The color-coded profile line corresponds to the elevations of vegetation zones. The profile lines that represent a SLR of one foot show the elevated sea level on the left, while the vegetation zone ranges have been moved up along the profile to a location that is one foot higher than the current vegetation zones elevations.

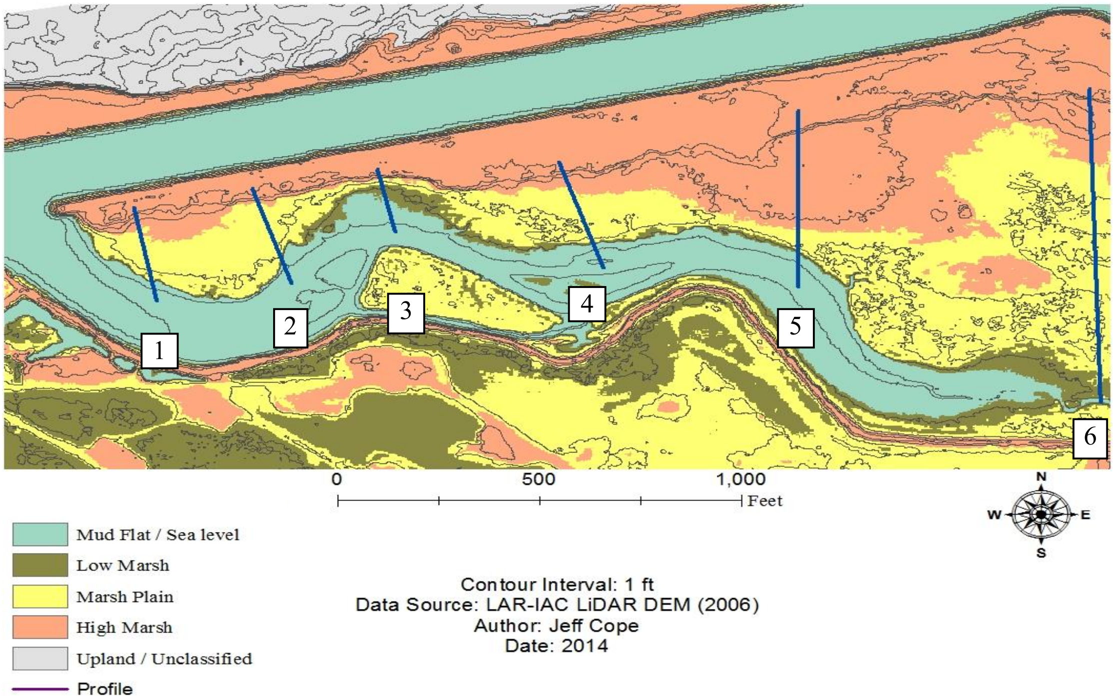

FIGURE 28. These six elevation profiles represent approximate locations of the survey locations and offer an enhanced perspective of the topography of the marsh

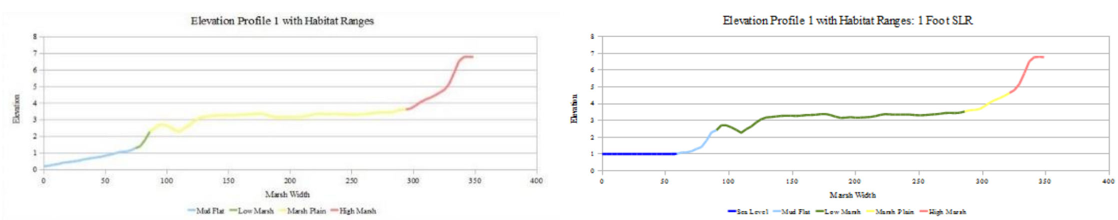

FIGURE 29. Elevation profile 1 with modern vegetation zones and vegetation zone after 1 foot of SLR.

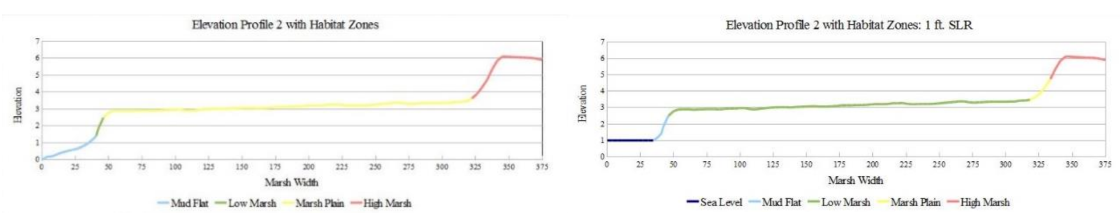

FIGURE 30. Elevation profile 2 with modern vegetation zones and vegetation zones after 1 foot of SLR.

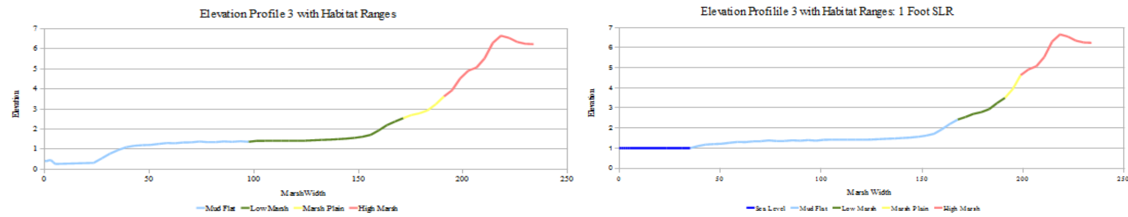

FIGURE 31. Elevation profile 3 with modern vegetation zones and vegetation zones after 1 foot of SLR

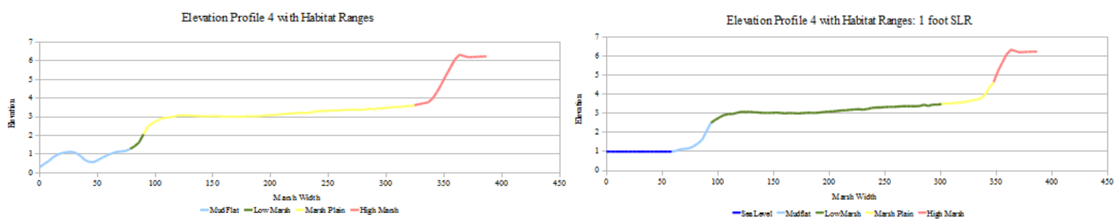

FIGURE 32. Elevation profile 4 with modern vegetation zone and vegetation zones after 1 foot of SLR

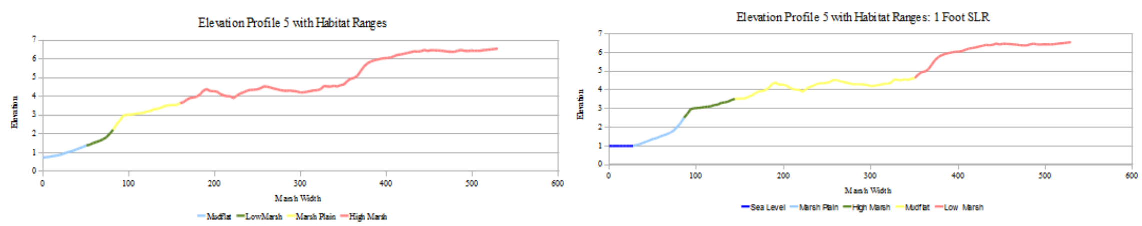

FIGURE 33. Elevation profile 5 with modern vegetation zones and vegetation zones after 1 foot SLR

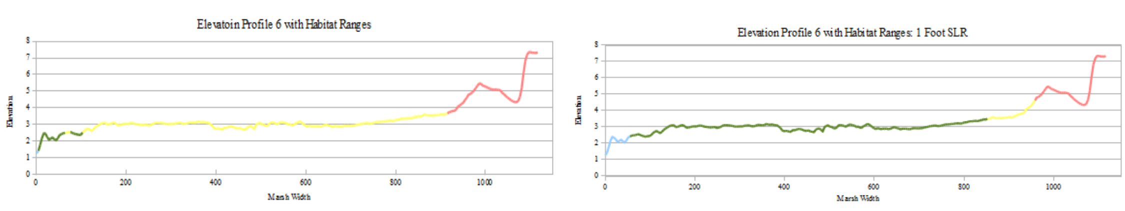

FIGURE 34. Elevation profile 6 with modern vegetation zones and vegetation zones after 1 foot SLR

CHAPTER 5

DISCUSSION

Steamshovel Slough is an ecosystem on the brink of significant change. Regardless of the degree of SLR that occurs during the next millennia, this coastal salt marsh is going to be dramatically different. Each vegetation zone will migrate away from rising sea level and into the artificial elevation gradient that constrains the marsh, at which point they will be squeezed down to thin bands that stretch for the total length of the marsh. As a result of the migration, each vegetation zone will have opportunities to thrive as the environment changes; however, considering the incessant march of rising tides, these opportunities are bound to be eliminated in time by the relentless climb of the sea. The survivability of vegetation zones in Steamshovel Slough and the associated ecological niches will depend on the rate and extent of SLR and the local topography throughout the marsh.

Current Vegetation

Vegetation zone elevations remained consistent throughout the entire marsh and GIS rendering of these zones was consistent with the marsh upon ground truthing. The range for *Arthrocnemum subterminale* was well above the range expected, which was based on Zedler's (1999) assessment of salt marsh vegetation elevation. The locations that *Arthrocnemum subterminale* reached above expected ranges were areas where the marsh had pronounced elevation gradients. It is possible that in the areas of steep artificial gradients, the individual plants possess a greater motility because of their proximity to higher elevation. For example, a large individual plant on the steep slope of an artificial gradient may drop seeds on the upslope side of the plant that are several inches above the maximum elevation typical of the species while dropping seeds on the downslope side of the plant that are within the range of elevation of the marsh plain. *Spartina foliosa* exhibited expected elevation ranges and was also associated with locations of topographic heterogeneity along the bayward edge of the marsh and along stream channels as Zedler (1999) observed.

One Foot SLR

Any species associated with *Spartina foliosa* and the low marsh stand will benefit markedly from the expansion of the low marsh. This expansion will occur in the near future as the marsh plain is gradually subjected to greater levels of inundation caused by rising sea level. The endangered Clapper rail, yet unseen in Steamshovel Slough, nests exclusively among the tall leaves of *Spartina foliosa.* This scenario will create expansive habitat for this species. Another important ecological impact will be the effect of 62% of high marsh giving way to the low marsh. This will result in a dramatic reduction in the most biologically diverse vegetation zone in the marsh. Most notably, this scenario will reduce the amount of habitat available for *Salicornia pacifica*. This marsh plain plant is the exclusive nest site for the endangered Belding's Savannah Sparrow. Locations throughout the marsh will provide landscape with an elevation matching that of the current marsh plain. The marsh plain in the eastern section of the marsh has a reduced gradient, upon a SLR scenario of 1 foot this area will be at the elevation of the current marsh plain. Also, the topographic rise in the eastern marsh plain will occupy a elevation equal to that of the current marsh plain as well. These areas of topographic heterogeneity express the importance of topographic complexity in the long-term sustainability of Steamshovel Slough.

Two Foot SLR

The large gain in low marsh habitat expected in the one-foot scenario is paralleled in the two-foot scenario by a significant reduction in low marsh. *Spartina foliosa* and the associated species will exist only along the reduced elevation gradient and topographic rise in the eastern plain. Less than half of the current marsh will be vegetated in this scenario. Habitat loss for every species except those few associated with the high marsh is expected. Once SLR reaches this level, Steamshovel will be mostly aquatic and mudflat, creating less of a restoration project and more of a habitat establishment project. As reflected in the one-foot scenario, the only area supporting vegetation is the reduced elevation gradient and elevated area in the eastern marsh plain.

Three foot SLR

Under the three-foot scenario the vegetation in the marsh exists mostly in the thin band of vegetation along the artificial elevation gradient at the inland side of the marsh. Low marsh and marsh plain species will be forced away from Steamshovel. The only vegetation zones existing in lower elevation ranges is low marsh at the highest extent of the reduced elevation gradient in the eastern plain, again exemplary of the importance of variation in topography elevation.

Suggestions for the Creation of a Sustainable Marsh

The data obtained here is useful for the management of a coastal salt marsh. Fundamental facets of salt marsh zonation have been identified and can be replicated by restoration mangers under consideration of expected global changes. Two primary conclusions arise from the results of the surveying and spatial analysis of Steamshovel Slough that hold utility to the construction of an adaptable and sustainable marsh in the face of the uncertainty of SLR.

1) It is immediately apparent that every region of the marsh with lightly sloping terrain has a greater spatial distribution of the vegetation zones. The adherence to elevation above sea level that species exhibit make this element of salt marsh ecology of paramount importance. The elevation profiles highlight the susceptibility of vegetation zones to variations in topography. Additionally, the spatial analysis of topography and ground truthing of these results indicate that vegetation zones are more expansive in areas with greater topographic complexity. As the modeling of variations of SLR indicates, the areas of slight relief will continue to occupy large areas of habitat when vegetation zones begin to migrate. The relationship these vegetation zones share with elevation and tidal influence, and not to edaphic and other ecological conditions, and the ability of salt marsh species to migrate inland and upland to maintain an equilibrium in elevation suggests that the creating of a more uniform elevation gradient throughout the marsh is a significant topographic adjustment to encourage longevity in the system.

2) Topographic heterogeneity encourages the occurrence of multiple vegetation zones throughout the marsh. The best indications of the ability of topographic

heterogeneity to support this biological variation throughout the SLR process is the results of SLR modelling around the island of raised topography in the eastern plain of the marsh. During the modelling process, each one of the scenarios tested revealed that a section of the small topographic rise provided habitable elevation for vegetation zones that were subject to coastal squeeze along the steep artificial elevation gradient.

One option in the creation of this type of habitat would be to develop topographic rises that run perpendicular to the orientation of vegetation zones. This could provide the opportunity for zones to migrate along the appropriate elevation gradient without the need to traverse breaks in their habitat range that would be created if topographic rises were placed parallel to the shoreline. It could also provide a greater length of surface for habitat, particularly in the low marsh, the way a circuitous coastline possesses more area of coast than a straight coastline. An example of this effect is along the creek-like feature at the eastern reach of the marsh, which allows for large areas of *Spartina foliosa* away from the bayward edge of the marsh, just as Zedler (1999) recognized in natural marshes near in Southern California.

Limitations of Research

With levels of uncertainty at play in the assessment of SLR along the California coast, it is necessary to mention a few compounding factors. Additionally, the process of collecting data in the field presented a factor that requires acknowledgment as a challenge to this research.

Levels of Accretion

The elevation of landscapes along the coast are subject to multiple mediums of change that may compound measurements of elevation relative to sea level, particularly in cases of extreme elevation sensitivity, such as this research. One factor that can cause elevation changes in a wetland is marsh vertical accretion. Accretion is the process of gradual elevation increase through deposition. The level of accretion of organic and inorganic material in marshlands has the ability to offset SLR impacts to a certain degree at some locations (Baustian et al. 2012; McKee et al. 2007). Vertical accretion occurs through the deposition of organic or inorganic material throughout the wetland. As vegetation, algae or animal life dies or decays it deposits throughout a marsh. Layer upon layer of this material build to create a dynamic elevation. Additionally, lithic or edaphic particles carried into the wetland via tidal exchange or deposited as river sediment add additional elevation to the coast. Cahoon et al. (1996) document the varying annual range of marsh accretion for a southern California marshland. The low marsh rates for the study period range between 2 and 8.5cm per year but were subject to above average rain events for the research period. High-marsh rates were a slight 1-2mm per year. Accretion rates for both the high marsh and low marsh prove to be almost entirely linked to episodic above average storm events, and it is noted that with typical precipitation patterns, the estuary would have far less if any vertical accretion.

The estuarine influence at Steamshovel Slough is much smaller than that of the Tijuana estuary where Cahoon et al. (1996) performed their elevation and accretion studies. The heavily channelized San Gabriel River once fed the Los Cerritos Wetlands; now, it empties directly into the Pacific Ocean away from the opening of the Alamitos Bay, which is the inlet for the tidal influence of Steamshovel Slough. This minimizes deposition of alluvial material from the river. Cahoon noticed a reduction in long shore alluvium deposition along in the Tijuana estuary because the estuary opening faced away from the direction of incoming sediment flow. Similarly, deposition of sediment travelling in long shore flows into Steamshovel is restricted if not completely muted by the development around the mouth of the bay and the circuitous path that tides must take to enter the wetlands. Additionally, Cahoon posits that under the drought conditions, to which southern California is highly susceptible, accretion rates fall dramatically relative to the measurements he acquired during his unseasonably wet research period. For these factors, the vertical increase of elevation is probably inconsequential to the research results.

Vertical Uplift and Subsidence

As previously noted, it is a common practice to locate areas of tectonic inactivity for research into sea level rise. The reliance upon a stable tectonic platform from which to research the effect of rising sea level and elevation is of significant importance in this tectonically active region. It is necessary to consider local tectonic forces and causes for vertical ground motion. While seismicity can produce marked vertical displacements, probably of greater concern here is local subsidence due to subsurface fluid removal. Oil extraction in the Long Beach area began in the 1890’s and ground water extraction first occurred in the 1940’s. The land began to subside because of this heavy extraction of subsurface fluid. This anthropogenic driven subsidence is a result of a reduction in upward pressure due to the removal of the weight baring subsurface fluids. As pressure opposing the overlying weight reduces, the aquifer begins to compact and the surface level of the land begins to drop (Shagam, 1999). By 1945, areas of Long Beach had dropped nearly 4 feet in elevation. The City of Long Beach, Gas & Oil Department (2014) reported that the area of Steamshovel Slough had subsided approximately 1.2 feet by 1974 but had stopped its vertical movement as a result of subsidence mitigation aided by the 1958 California Subsidence Act. Though subsidence would amplify the results of this thesis the surface elevation of this area of Long Beach is currently static.

CHAPTER 6

CONCLUSION

Sea level rise and the process of coastal squeeze will continue to threaten coastal communities and ecosystems around the planet regardless of the exact degree of SLR. Uncertainty obscures the degree of SLR, making mitigation and management decisions challenging. This research attempted to define expected vegetation shifts in a southern California coastal salt marsh and aspired to identify appropriate sea level rise mitigation efforts through analysis of vegetation zone elevations, and modeling of those vegetation zones when responding to varying degrees of SLR. The results are accurate approximations for the elevation of three vegetation zones for Steamshovel Slough and reveal that marsh topography plays an essential role in future location of vegetation zones. Most significantly, a minimum of one foot SLR will cause a dramatic shift of vegetation zones throughout the entire marsh. The low marsh will benefit greatly from SLR while the marsh plain suffers unequivocally. If SLR were to reach two feet, another significant shift may occur. The low marsh will retreat and mud flat will claim a majority of the vegetated space in the marsh. The results show that a SLR of greater than two feet will inundate the vast majority of the marsh and render mitigation efforts mostly useless.

Regrettably, due to the relentless rise of sea level and the fact that despite the construction of a marsh that makes every known accommodation towards SLR, the marsh will eventually be susceptible to tides of change. This renders the known vegetation zone elevations rather ineffectual for restoration ecology. Considering the anticipated rise of sea level for the next several hundred years, applying restoration techniques that target the occupation of vegetation zones at specific elevations or according to specific SLR scenarios would be to assign an expiration date to the marsh. The goal of mitigation efforts may benefit markedly by focusing efforts on the foundation of biodiversity in the coastal salt marsh, the shape and layout of marsh topography in general, and its relationship with tidal influence. To do this, focus must be placed on topographic heterogeneity with several feet of topographic relief.

The most applicable results found here indicate that a gradual topographic profile with the aforementioned topographically heterogeneous areas stands to provide the greatest opportunity for the upward migration of vegetation zones responding to unrelenting SLR. Additionally, the methodology applied here presents a simple approach to elevation surveying and spatial analysis of coastal salt marshes that should be repeatable with minimal technological support.

The degree of sea level rise will remain uncertain. Given as much, restoration ecology managers and any environmental consultants working with coastal salt marsh ecology must base decisions on verifiable and tangible evidence that can inform an adaptable and reliable plan regardless of the future environmental changes. The goal of this research has been to apply an innovative yet simple and repeatable methodology for collecting data for the modelling of sea level rise scenarios in a confined coastal salt marsh. The research intends to help develop part of a pragmatic and prosaic plan for a sustainable environment in the face of a changing planet.

It is certainly confounding that, even among established and published experts in salt marsh ecology, a determination of key ecological factors controlling salt marsh vegetation zones has yet to be established. A better understanding of the controlling factors of salt marsh vegetation, other than elevation, is strongly encouraged. Additionally, any relationship between the pace of SLR or the slope angle of topography with the ability for coastal salt marsh vegetation migration is strongly encouraged. Because the rate of SLR is anthropogenic, it is conceivable that SLR may outpace the natural ability of a marsh to adapt. The aforementioned relationships may assist or hinder migration ability. Such supplementary research objectives may offer improvement on the development of a sustainable salt marsh by offering more tools applicable in the establishment of a healthy and adaptable ecosystem.

APPENDIX

ACCURACY ASSESSMENT RESULTS

Adjacent	Inclination	Sin angle	Opposite	Inclination	Sin angle	Opposite
540	6.7	0.11667	63.00	6.6	0.11494	62.07
540	6.8	0.11840	63.94	6.6	0.11494	62.07
540	6.8	0.11840	63.94	6.3	0.10973	59.26
540	6.8	0.11840	63.94	6.8	0.11840	63.94
540	6.4	0.11147	60.19	7.0	0.12187	65.81
540	6.8	0.11840	63.94	6.8	0.11840	63.94
540	6.9	0.12014	64.87	6.8	0.11840	63.94
540	6.6	0.11494	62.07	7.0	0.12187	65.81
Average			63.24			63.35
					Eye level	63.00
540	6.2	0.10800	58.32	6.4	0.11147	60.19
540	6.4	0.11147	60.19	6.4	0.11147	60.19
540	5.6	0.09758	52.69	6.1	0.10626	57.38
540	6.0	0.10453	56.45	6.4	0.11147	60.19
540	6.0	0.10453	56.45	6.4	0.11147	60.19
540	6.1	0.10626	57.38	6.4	0.11147	60.19
540	6.4	0.11147	60.19	6.0	0.10453	56.45
540	6.2	0.10800	58.32	6.4	0.11147	60.19
Average			57.50			59.37
					Eye level	59.00

Note: The results of the accuracy assessment for the tape measure and Nikon surveying technique show the accuracy of the method for several tests in two directions and from two Nikon operators. These measurements were taken at Steamshovel Slough.

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