ABSTRACT

PLANT COMMUNITY

AND SEDIMENT DEVELOPMENT IN TWO

CONSTRUCTED SALT MARSHES IN LONG BEACH, CALIFORNIA

By

Melissa Marie Apodaca

December 2005

Restoration practices have increased in recent years due to the continued degradation of wetland habitat. The goal of this project was to evaluate 2 constructed salt marshes of different ages in southern California by examining the plant community and sediment conditions. Diverse plant cover at the younger marsh increased over time but remained lower than levels at a natural marsh. Plant cover at the older marsh had reached the levels at the natural marsh, however plant diversity remained low. Both marshes contained coarse sediments with low organic matter. While vegetative cover appears to be developing properly at both constructed sites, other attributes remain different from the natural marsh. Low plant diversity at the older marsh and the sediment conditions at both marshes may have implications for faunal and floral community development. Continued monitoring will be necessary to ensure that these marshes continue to develop properly.

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WE, THE UNDERSIGNED MEMBERS OF THE COMMITTEE,

HAVE APPROVED THIS THESIS

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CHAPTER 1

INTRODUCTION

Salt Marsh Restoration

Salt marshes carry out many important functions in coastal ecosystems. The high rates of primary production by both vascular plants and algae in marshes are important in coastal food webs and help to maintain a healthy ecosystem (Zedler 1996a). Salt marshes provide essential habitat for invertebrates, shorebirds, and fish, including many threatened and endangered species, such as the California least tern and Belding's Savannah sparrow, which rely on marshes for refuge and breeding grounds. In addition to promoting biodiversity, coastal marshes can remove excess nutrients and contaminants from the watershed before the water flows into the ocean (Zedler). Loss of these valuable habitats can have drastic negative effects on the coastal ecosystem, causing decreases in overall biodiversity and productivity.

There has been a dramatic loss of salt marsh habitat worldwide, especially on the west coast of North America. Estimations suggest that southern California has lost over 90% of its historic coastal wetland habitat (Langis, Zalejko, and Zedler 1991). This loss of habitat has been due to a variety of reasons, including hydrological changes and dredging and filling for agricultural or urban purposes (Grayson, Chapman, and

Underwood 1999). Government regulations now require lost wetland habitat to be replaced by creating or restoring at least an equal area of wetland habitat. Restoration efforts are particularly important in urban areas where there is little natural habitat left. Remaining marshes in these areas experience ongoing anthropogenic disturbance, are extremely fragmented, and have become severely degraded, raising the question as to whether they can ever be restored to a natural state (Grayson, Chapman, and Underwood). These degraded marshes have low percent vegetation cover and low species diversity, and do not carry out equivalent functions (e.g., support of fish and bird species) as undisturbed sites (Zedler 1996a).

The primary goal of restoration is to restore ecosystem function, especially for fish and bird species or water quality services, such as the removal of excess nutrients from the watershed (Zedler 1996b). Existing degraded sites can be restored to a more functional state, or new sites can be constructed where current marsh habitat does not exist. In southern California there are few salt marsh sites left to restore, thus most sites are created where there had historically been salt marsh habitat. Success of these sites is usually determined by comparing the vegetative cover in the restored site to a designated natural site, assuming that sites which are structurally similar will function similarly (Grayson, Chapman, and Underwood 1999; Kentula 2000). However, this is not always the case, due to continued human influences and lack of understanding of complex salt marsh functions (Simenstad and Thom 1996; Shuwen et al. 2001). As a result, inappropriate hydrologic, sediment, or nutrient conditions may be created, resulting in a marsh which does not function properly. In addition, restored or created sites are rarely compared to degraded sites, thereby making it difficult to determine the progress of the restoration (Grayson, Chapman, and Underwood). A variety of ecological parameters need to be examined when evaluating the habitat quality of restored or constructed sites, including: vegetative cover, plant diversity, sediment characteristics, and presence of exotic species, among others (Zedler 2000).

Past restoration efforts have shown that plant community recovery in constructed salt marshes can be highly variable and depends on a variety of factors including hydrology, sediment type, and organic content of the soil, among others. Plant cover and species present in constructed sites can become similar to natural sites in as little as 4 years (Simenstad and Thom 1996; Zedler 2000). Plant cover at Golden Shores Marine Reserve in Long Beach, California had attained an average cover of 94% after 5 years (Beck and Paquette 2003). However, this rapid expansion of plant cover does not always occur. A 5 year old site in Virginia had lower stem density and percent plant cover than nearby natural sites, which was primarily attributed to low organic content in the soil (Havens, Varnell, and Bradshaw 1995). After 12 years, stem density and percent cover, as well as most other attributes of the marsh (e.g., invertebrate use, soil salinity, and soil oxygen levels), had reached levels observed in nearby natural sites (Havens, Varnell, and Watts 2002). However, not all plant species became well established in the constructed site, and the organic content of the soil still remained low. Similar to the abovementioned Virginia site, a restored site in San Francisco had only 40% plant cover after three years as a result of inadequate tidal flow (Zedler 1996a). Sixteen years later, the marsh still had inadequate plant cover and productivity, and estimations project that it may take more than 60 years for this site to become stable. Simenstad and Thom (1996) found the plant community of a constructed Washington State salt marsh to be unstable after 7 years. This instability was attributed in part to changes in elevation and differing competitive ability of the plant species in the marsh. Thus, a marsh may appear to have developed to natural levels only to change due to shifts in hydrology, sedimentation, or natural succession within the plant communities (Simenstad and Thom).

The large amount of open space in newly constructed salt marshes should provide more habitat for seedling establishment, which may aid vegetative expansion. In mature salt marshes, seedlings often play little to no role in aboveground plant dynamics, with germination only occurring in cleared plots (Allison 1996; Hopkins and Parker 1984; Huiskes et al 1995; Lindig-Cisneros and Zedler 2002). This results from the dominant perennial vegetation relying on vegetative reproduction via rhizomes rather than sexual reproduction. If seeds are to be comparatively more important in constructed marshes, a seed bank must become established. Urban marshes are usually small and isolated, which may prevent dispersal of seeds between marshes. It has been found that few seeds are transported out of salt marshes due to negatively buoyant seeds and vegetation trapping seeds that float (Huiskes et al; Lindig-Cisneros and Zedler). Given the large distances between urban marshes and the low out-flux of seeds from marshes, it is unlikely that constructed sites will receive seeds from other marshes. As a result, constructed sites need to establish a seed bank from within the marsh. Once a seed bank becomes established, successful seedling recruitment may allow for increased vegetative expansion.

Establishment and spread of salt marsh plant species will depend on their tolerance for inundation and salinity. Variability in tolerance to these factors results in different plant species becoming established in specific elevation ranges (Pennings and Callaway 1992; Lindig-Cisneros and Zedler 2002). This pattern of establishment results in distinct and predictable vegetation zones in a salt marsh. Within southern California salt marshes, there are three distinct plant zones: lower (approximately 0.9-1.2 m above mean lower low water; MLLW), middle (approximately 1.2-1.8 m above MLLW), and upper (approximately 1.8-2.1 m above MLLW; Vogl 1966; Zedler 1982). Plant species in the lower marsh zone readily tolerate inundation but not high salinity, while plant species in the upper zone do not tolerate inundation but do tolerate high salinity soil (Pennings and Callaway 1992). The lower marsh is occupied primarily by *Spartina foliosa*, while the more diverse middle zone consists primarily of *Salicornia virginica*, *Jaumea carnosa, Batis maritima, Frankenia salina, Suadea* sp.*, Triglochen concinna* and *Limonium californicum*. This high diversity is a result of the less extreme conditions (i.e., lower salinity than the high marsh and less inundation than the low marsh) found in the middle zone (Pennings and Callaway). *Salicornia subterminalis*, *Monanthochloe littoralis, Juncus* sp.*,* and *Distichlis spicata* are the most common species found in the high marsh. This distinct plant zonation is extremely sensitive to changes in elevation, with a change of as little as 10 cm resulting in a vegetative shift (Zedler).

Exotic species often invade disturbed habitats, making restored and constructed sites prime habitat for invasion. In these sites, the exotics may invade open habitat (e.g., *Spartina alternaflora*) or displace native vegetation (e.g., ice plant species; Zelder 1996a; Havens, Berquist, and Priest 2003). Establishment of exotics in salt marsh habitats is often controlled by high soil salinity, periodic inundation, and dense canopy cover. Removal of these controls may facilitate the introduction of exotic species in salt marsh habitats. In newly constructed sites, where the canopy cover is low, exotic species may have an easier time invading. Havens, Berquist, and Priest found that sparsely vegetated areas were more easily invaded by *Phragmites australis* than areas that were more densely vegetated. Proper tidal flow in constructed and restored sites will also be important in controlling exotic species, as the exotics are often less tolerant of inundation than natives (Zedler). Newly constructed sites are often purposefully flushed with fresh water to facilitate plant establishment by lowering the soil salinity, however, this may also facilitate exotic plant establishment. In addition to the above reasons, urban wetlands are especially susceptible to invasion by exotic species due to their close proximity to residential and commercial developments (Zedler; Havens, Berquist, and Priest). This close proximity could allow exotics used in landscaping to spread into the marsh. Eradication of exotics from salt marshes can often be expensive and difficult due to the vegetative regeneration capabilities of many species and, thus, prevention of establishment is the best control (Zedler).

Sediment conditions are important for successful plant establishment in salt marshes and are often not given adequate attention during restoration. Nutrient retention in the soil is important in determining the rate of plant recovery in restored and constructed salt marshes affecting plant diversity and growth (Zedler 2000). Inadequate nutrient supply and retention could affect basic salt marsh functions (e.g plant production and habitat availability for insects and birds), altering the plant, invertebrate, fish, and bird communities of the marsh (Langis, Zalejko, and Zedler 1991). The nutrient content of the soil will depend, in part, on the composition of the sediment, because sandy soils retain fewer nutrients while finer sediments retain more nutrients. Constructed sites often have coarser soils than natural sites due to the frequent use of upland soils in the creation of salt marsh sites (Zedler 1996a). While salt marshes accumulate organic matter over time, the development of organic sediments can take centuries or millennia (Zedler).

Until adequate organic soils accumulate in constructed marshes, basic marsh functioning will be affected. *Spartina foliosa* in a constructed marsh in San Diego grew shorter due to low nitrogen levels resulting from sediment that was too coarse (Zedler and Langis 1991). Similarly, a constructed site in British Columbia had inadequate plant expansion due to low organic content of the coarse soils (Zedler). Willis and Mitsch (1995) found that nutrient levels did not affect emergence of plants, but did affect biomass and growth after emergence. Thus, total cover may be similar to natural marshes but canopy structure may be different.

The length of time it takes for nutrient levels in constructed marshes to reach levels found in natural marshes varies dramatically. At a Texas constructed site, it took 2 to 5 years for nutrient levels to reach reference levels (Lindau and Hossner 1981), while reference levels were not reached until year 15 in a constructed marsh in North Carolina (Craft, Boome, and Senca 1988). Langis, Zalejko, and Zedler (1991) found that nutrient levels in a constructed site in San Diego were still low after 5 years due to high mineralization rates, which resulted in low organic matter accumulation in the marsh. The development of adequate nutrient levels in constructed and restored sites can be affected by the geographic location of the site. The Tijuana Estuary in San Diego has low nitrogen levels, which may partially be a result of its location in a Mediterranean climate (Langid, Zalejko, and Zedler). The low and variable amount of rainfall in southern California results in low nutrient input into the salt marsh from the watershed. In the Tijuana Estuary, the nitrogen input from tidal flow was not enough to account for the nitrogen required by the plants, leading Langis Zalejko, and Zedler to suggest that rapid nutrient cycling or high rates of nitrogen fixation must occur in southern California marshes to account for the high nitrogen demand by the plants that grow in these marshes. It has been found that southern California salt marshes contain high levels of sedimentary microalgae, consisting of cyanobacteria, diatoms, and filamentous algae (Zedler 1982). Langis Zalejko, and Zedler suggested that the high levels of algal mat cover on the West Coast may result in higher nitrogen fixation rates than on the East Coast, which could have a positive effect on plant recovery in restored and constructed western sites.

Goals of This Study

In the past 8 years 2 small salt marshes have been created in Long Beach, California: Golden Shores Marine Biological Reserve and Jack Dunster Marine Biological Reserve. Golden Shores, a 6.4-acre marsh built in 1998, was created as a mitigation site by the Aquarium of the Pacific to compensate for building over salt marsh habitat. Because this site was a mitigation project, planning for the site was such that the mitigation terms would be met within 5 years. As part of the mitigation terms, the species composition of the vegetation, as well as faunal communities, in the marsh were monitored for the first 5 years. However, no evaluation has been conducted in this site since 2002. Jack Dunster, a 1.5-acre marsh, was built in 2000 as a tribute to Jack Dunster, an avid salt marsh enthusiast. The design for this site was based on a nearby natural marsh and the goals were to recreate the vegetative community seen at the natural marsh. Because this site was not built for mitigation purposes, no monitoring has been conducted. The City of Long Beach is currently examining plans to restore and create further salt marsh habitat in Long Beach. Thus, there is a need to evaluate the current state of these 2 created sites. This evaluation could provide insight into how to improve current and future restoration sites.

The goal of this project was to gain an understanding of the plant community dynamics at Golden Shores Marine Biological Reserve and Jack Dunster Marine Biological Reserve in Long Beach, California. This was accomplished by examining vegetative percent cover, plant diversity, the seed bank composition, as well as sediment organic content and grain size in the 2 constructed sites, a naturally occurring salt marsh and a degraded marsh. I hypothesized that:

1. Golden Shores would have a similar percent vegetative cover to the natural marsh while Jack Dunster will have lower vegetative cover.
2. Vegetative cover at both constructed marshes would be higher than at the degraded marsh.
3. The species diversity at both constructed marshes would be lower than at the natural marsh but higher than at the degraded marsh.
4. The seed bank size would be positively correlated with the age of the marsh.
5. The natural marsh would have higher sediment organic content and finer sediment than Jack Dunster, Golden Shores, or the degraded marsh.

CHAPTER 2

MATERIALS AND METHODS

Study Sites

Jack Dunster Marine Reserve is a small salt marsh (1.5 acres) built in 2000 along the Los Cerritos Channel in Long Beach, California (figure 1). Prior to construction, the site consisted of a dirt bank overgrown with weeds. Upland soil from Riverside County in southern California was used to create both salt marsh and upland habitat. The marsh portion, which now receives full tidal flushing, was terraced to create high, mid, and low marsh habitats and planted with native vegetation (Arkenstall, pers. comm.). This site was designed to mimic the nearby natural Los Cerritos Wetlands and all marsh plants were grown from cuttings taken from the Los Cerritos Wetlands (table 1). The site was heavily irrigated with fresh water during the first year. Due to extensive establishment of exotics after the first year, managers decided to hand water once a month. A floating boardwalk was placed between the marsh and the channel to reduce erosion from the currents and boat activity in the channel. The site occurs directly adjacent to a housing development and contains a path through the upland portion of the reserve and a gangway that allows access to the floating boardwalks. Once the site was planted, no quantitative data were collected on the development of the site. Qualitatively, the marsh plants expanded yearly from planting in 2000 until this project started in 2004 and the site was frequented by various shorebirds (Arkenstall pers. comm.). However, in the winter of

2003-2004 the *Spartina foliosa* population experienced dramatic dieback of almost 100%, but all other plants appeared to be healthy.

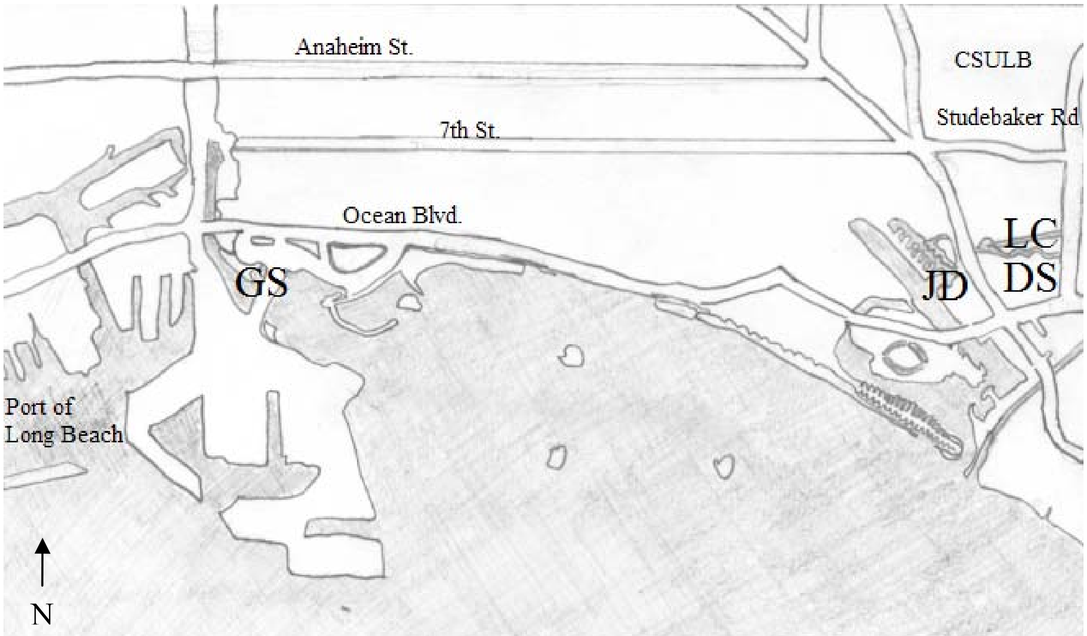

FIGURE 1. Location of Jack Dunster Marine Biological Reserve (JD), Golden Shores Marine Biological Reserve (GS), Los Cerritos Wetlands (LC), and the degraded marsh (DS) in Long Beach, California.

Golden Shore Marine Biological Reserve is a 6.4-acre salt marsh located off the Los Angeles River in Long Beach, California (figure 1). The reserve was created in 1997-1998 as a mitigation project for the Aquarium of the Pacific, which was built on previous salt marsh habitat in the Port of Long Beach. Golden Shore had previously been a boat launch and prior to construction was covered with cement. The marsh occurs directly below a recreational vehicle (RV) park near downtown Long Beach. No public access is allowed to the marsh itself, but there is a small municipal park located above the marsh next to the RV park. The site was excavated and upland soil from Riverside County, California was brought in to create the marsh habitat, which now receives full tidal flushing. Marsh vegetation was planted in early 1998. The vegetation chosen represented species that are known to expand quickly, and would thus allow the mitigation terms to be met in the 5 year period. The site was originally created with low-to-mid marsh habitat (4.0 to 5.0 ft above mean low low-water; MLLW) and mid-to-high marsh habitat (5.0 to 5.4 ft above MLLW; Paquette 1999). However, erosion during the first year resulted in the site having an extremely gentle slope that did not attain the elevation needed for upper marsh habitat development. Thus, the site is now primarily composed of middle and low marsh habitat. During the first 3 years (1998-2000) the site continued to experience changes in elevation resulting from erosion, deposition, and redistribution of sediments (Beck and Paquette 2001). There was a large amount of sand deposited near the mouth of the Reserve during the first year due to a sand bar located in the River just outside of the Reserve. The sand deposition continued through out the entire 5 years the site was monitored. By year 5 (2002), there were still slight changes in elevation throughout the marsh but sediments appeared to be stabilizing (Beck and Paquette 2003). Managers suggested continued dredging near the mouth to remove the sand that was being deposited. Due to the changes in elevation, the high marsh vegetation (*Distichlis spicata, Monathochloe litoralis, Limonium californicum,* and *Frankenia salina*) died out during the first year. During the second year, mid marsh plants *Saliconia virginica, Frankenia salina, Batis maritima,* and *Jaumea carnosa* were planted in the area that was previously high marsh habitat to replace the high marsh vegetation that died. *Spartina foliosa* was not initially planted because it was believed that it would not do well. However, in 2000 *S. foliosa* was introduced into a small area of the marsh (Beck and Paquette 2001). After the initial introduction, *S. foliosa* expanded into other areas of the marsh. During the entire 5 year period the marsh was monitored, the fish, invertebrate, and bird populations continued to increase. However, by 2002 the invertebrate community remained low and managers believed that it would take several more years for the invertebrate community to reach maturation (Beck and Paquette 2003).

TABLE 1. Species Initially Planted at Jack Dunster Marine Reserve in 2002 and Golden Shores Marine Reserve in 1998

	Jack Dunster	Golden Shores
Distichlis spicata	X	X
Salicornia subterminalis	X	X
Monathochloe litoralis	X	X
Salicornia virginica	X	X
Frankenia grandifolia	X	X
Suadea sp	X	
Limonium californicum	X	X
Jaumea carnosa	X	X
Batis maritime	X	X
Triglochen conicinna	X	
Spartina foliosa	X	X*

**S. foliosa* was not planted at Golden Shores until 2000 (3 years after the marsh was created).

The Los Cerritos Wetlands are historic salt marshes located off the Los Cerritos Channel in Long Beach, California (figure 1). The wetlands were historically 2400 acres but have currently been reduced to 19 acres of salt marsh habitat. Loss of wetland habitat was primarily due to urban and industrial development. The marsh is currently bordered by oil fields, housing, and commercial developments. This mature, non-degraded, functioning marsh receives full tidal flushing through an opening to the Los Cerritos Channel. A floating boom was placed across this opening to reduce trash flow into the marsh. There is no public access to the salt marsh habitat. However, there is boat activity in the channel leading into the salt marsh.

Directly adjacent to the functioning Los Cerritos salt marsh are oil fields that were previously part of the larger Los Cerritos Wetlands (figure 1). This area is severely degraded, but does include areas that receive restricted tidal flow and are populated by salt marsh vegetation. The elevation at this site is appropriate for mid and high marsh habitat. In the 1980s there were plans to restore areas around the functioning salt marsh which, to date, have not been implemented. Property owners are currently discussing future plans for the site.

Plant Community

Transects were set up perpendicular to the water line throughout the entire marsh at Golden Shore (GS) and Jack Dunster (JD). At Los Cerritos (LC), transects were set up in the back portion of marsh where all 3 marsh zones were present. Transects were also set up in a portion of the degraded marsh (DS) behind the active oil fields and adjacent to the Los Cerritos site. Transects were placed 20m apart at GS due to the large area sampled, and 10m apart at JD, LC, and DS. Thus, there were 14 transects at GS, 9 at JD, 10 at LC, and 8 at DS. At JD and LC one permanent $1m^2$ quadrat was randomly placed in each of the high, mid, and low marsh zones along each transect line. Due to the lack of strict zonation at GS and DS, $1m^2$ quadrats were placed every 10m along each transect, ensuring that the entire vegetative habitat was covered. Measurements of % cover of each species present in the quadrats were made once a month from April 2004 to June 2005 by visually estimating the percent cover of each species in the quadrat. No data were collected in January 2005 due to heavy rains. Each quadrat was divided into 24 equal squares and the number of squares each species filled was determined. For each species, the number of squares filled was divided by 24 to determine the % cover. The measurements were taken by the same person every time to reduce human variability. Vegetative diversity was calculated for each quadrat using species richness (S) and the Shannon-Weiner Index (H′; Zar 1999).

$$S = total\#species \qquad [1]$$

$$H' = -\sum_{i=1}^{k} p_i \ln p_i \qquad [2]$$

p_i = proportion of observations in category i

k = number of categories

Differences in % cover were analyzed using GLM with site, month, and zone as factors, followed by Tukey-Kramer tests. Data were arcsine-square root transformed prior to analysis. Because not all sites contained all 3 marsh zones, there were a large number of empty cells. Therefore, 3 GLMs were run as follows: 1). Jack Dunster and Los Cerritios all 3 zones, 2). Jack Dunster, Golden Shores, and Los Cerritos mid and low zones only, and 3). Jack Dunster, Los Cerritos, and the degraded site high and mid zones only. This set-up allowed all possible comparisons without having empty cells. Because multiple test were run, α was adjusted using the Bonferroni method (Zar, 1999).

$$\alpha^* = \frac{0.05}{3} = 0.017 \qquad [3]$$

Seed Bank Dynamics

Ten sediment cores (5cm diameter, 5cm long) were randomly taken from each zone at each marsh in October 2004 and March 2005. No cores were taken within 1 meter of the permanent quadrats. Each core was emptied into a plastic container with drainage holes and placed in a growth chamber for 9 weeks with a 12:12 light/dark cycle. The temperatures in the growth chamber were altered every 3 weeks to reflect the average daily high and low temperatures in Los Angeles County for April (22°C/12°C), May (23°C/14°C), and June (25°C/16°C; National Oceanographic and Atmospheric Administration 2004). The containers were watered with 10 ml tap water every other day while they were in the growth chamber. After 9 weeks, the containers were transferred to a green greenhouse while the seedlings matured for accurate identification. Due to excessive drying in the greenhouse, the containers were placed in large plastic trays that were filled with tap water.

Sediment Characteristics

Three sets of 2 sediment cores (5cm diameter, 20cm long) were randomly taken in each zone at each marsh in November 2004 and May 2005. Thus, for each month there were 6 cores for each zone at each site. The 2 cores in each set were taken directly adjacent to each other. No cores were taken within 1 meter of the permanent quadrats. One core from each set was used for organic content analysis and the other was used for grain size analysis. For both organic content and grain size analysis, each core was divided into four 5cm sections in order to determine how the sediment changed with depth. Grain size characteristics were determined using a Beckman Coulter LS 13 320 Laser Diffraction Particle Size Analyzer. Bulk samples were run for 90 seconds using the wet module with a 1% soap dispersant solution. The dispersant was made with 50g sodium metaphosphate, 7g sodium carbonate, and 1L deionized water. This solution was diluted to a 1% solution with deionized water when added to the sample. Grain size mode as well as % sand, silt, and clay were determined. Percent mud was determined by combing the % silt and clay fractions.

$$\%mud = \%silt + \%clay \quad [4]$$

Organic content of the soil was determined by drying the cores to a constant weight at 60 °C and then placing them in a muffle furnace at 550 °C for 2 hours. Organic content was calculated as % ash free dry weight (%AFDW) using the following equation:

$$\%AFDW = \frac{AFDW}{DW} \quad [5]$$

$$AFDW = DW - AW \quad [6]$$

AFDW = ash-free dry weight = combustible material burnt off during burning

AW = ash weight = non-combustible material left after burning

DW = dry weight = weight after dried to a constant weight

Grain size mode was analyzed using GLM with site, month, zone, and depth as factors followed by Tukey tests. The raw data did not pass the F_{max} test and thus were natural log transformed prior to analysis. The initial GLM showed that month was not significant and therefore the data were pooled across month. Percent AFDW and % mud of the sediment were analyzed using GLM with site, month, zone, and depth as factors followed by Tukey tests. Both % organic content and % mud data were arcsine-square root transformed. For both AFDW and % mud, the initial GLM showed that month was not significant, thus data was pooled across month and the GLM was run with site, zone, and depth as factors. Because not all sites contained all zones, 3 GLMs were run for % AFDW, grain size mode, and % mud using the same set up as the vegetative cover with an adjusted α.

CHAPTER 3

RESULTS

Plant Community

In the surveyed marshes, % vegetative cover differed among marsh site ($p <$ 0.001), time of year ($p < 0.001$), and zone ($p < 0.001$). In addition, there were significant interactions between the effects of marsh site and time of year ($p < 0.01$) as well as marsh site and zone ($p < 0.001$). No significant interaction**s** were found between the effects of time of year and zone ($p > 0.05$) or between the effects of marsh site, zone, and time of year ($p > 0.05$).

Species richness varied among marsh site ($p < 0.001$) and zone ($p < 0.001$). In addition, there was interaction between the influences of marsh site and zone ($p < 0.001$). Species diversity differed among marsh site ($p < 0.001$) but not time of year ($p > 0.1$) or zone ($p > 0.1$). The only significant interaction of environmental factors on species diversity occurred between the effects of marsh site and zone ($p < 0.001$). Because the low marsh zone at the 5 year-old marsh (JD) only contained *Spartina foliosa,* the variance for that site was 0, which prevented passing of the F_{max} test for this zone. Therefore, species richness and diversity were only examined statistically in the mid and high zones.

Due to the significant interactions for vegetative cover, richness, and diversity, Tukey-Kramer tests were used to make specific comparisons among group means.

High Marsh Zone

With close to 100% cover, the high zone in the natural marsh (LC) had the highest vegetative cover, followed by the high zone in the 5 year-old constructed marsh (JD), while the degraded marsh (DS) had the lowest cover (Tukey-Kramer, $p < 0.05$; the 8 year-old site (GS) was not included because does not contain high marsh habitat; figure 2). There was no significant change in vegetative cover over time at any site (Tukey-Kramer, $p > 0.05$). The average vegetative cover of the 5 year-old site (JD) at the start of the study was 54.8 ± 13.9%. By the end of the 14 month period, the vegetative cover increased slightly, but not significantly to 65.7 ± 12.8% (Tukey-Kramer, $p > 0.05$). The vegetative cover at the natural marsh (LC) remained near 100% throughout the year, ranging from 93.8 ± 4.2% to 104.4% ± 5.8. In the spring and summer months the cover

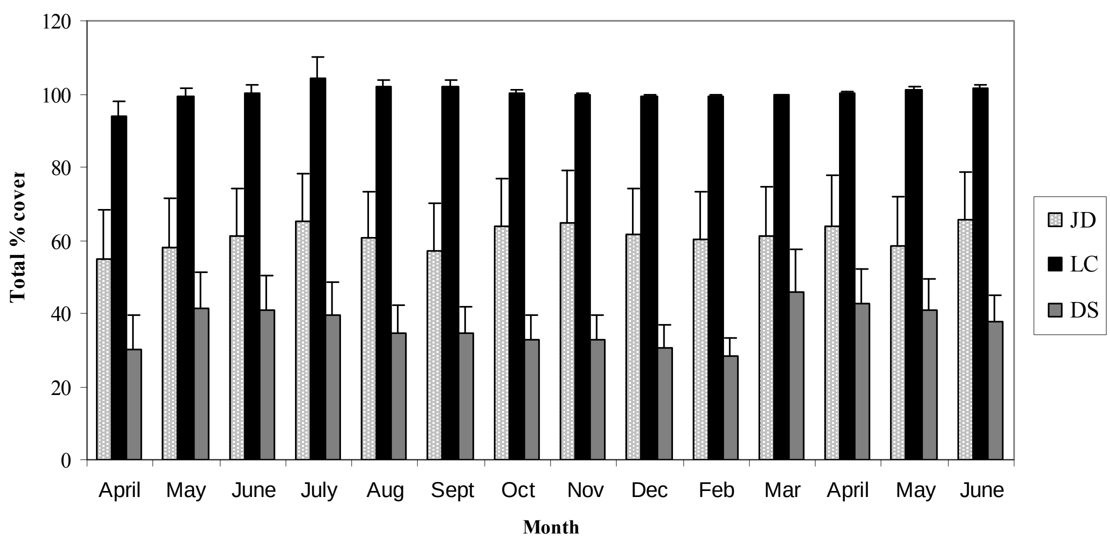

FIGURE 2. The vegetative cover (mean ± *S.E.*) from April 2004 to June 2005 in the high marsh zone of the 5 year-old constructed marsh (JD; $n = 6$), the natural marsh (LC; $n = 10$), and a degraded marsh (DS; $n = 8$). The 8 year-old constructed marsh (GS) was not included because it does not contain high marsh habitat.

at this marsh occasionally exceeded 100% due to the presence of *Cuscuta salina*. The vegetative cover at the degraded marsh (DS) fluctuated slightly throughout the 14 month period, ranging from 28.6 ± 5.2% to 45.8 ± 11.8%. The highest cover at this site was seen in the spring months when upland annuals were present, however this seasonal effect was not pronounced enough to result in a significant effect of time of year on % cover at the degraded marsh (DS; Tukey-Kramer, $p > 0.05$).

TABLE 2. Species Present (*p* = Perennial, A= annual) in the High Marsh at a 5 Year-Old Constructed Marsh (JD), an 8 year-Old Constructed Marsh (GS), a Natural Marsh (LC) and a Degraded Marsh (DS) From April 2004 to June 2005. GS Does Not Contain High Marsh Habitat.

Site	*Distichlis spicata*	*Salicornia subterminalis*	*Monathochloe litoralis*	*Cressa truxillensis*	*Salicornia virginica*	*Frankenia salina*	*Suaeda sp.*	*Limonium californicum*	*Jaumea carnosa*	*Batis maritima*	*Triglochin conicinna*	*Cuscuta salina*	*Salicornia bigelovii*	*Spartina foliosa*	Upland Grasses[a]	*Mesembryanthemum nodiflorium*[a]	Cumulative species richness
JD	P	P	P		P	P		P	P						A	A	9
LC	P	P	P	A	P	P	P	P	P			A					11
DS	P	P		A	P										A	A	6

[a] Denotes invasive species

There were 11 plant species in the high marsh zone of the natural marsh (LC), 9 in the 5 year-old constructed marsh (JD), and 6 species in the degraded marsh (DS; table 2). Two of the 9 species at the 5 year-old marsh (JD) were invasive, one being an upland grass species and the second being the exotic ice plant *Mesembryanthemum nodiflorium.* While the natural marsh (LC) also contained upland grasses in the upper marsh, there was no ice plant in the marsh itself. The degraded marsh (DS) contained upland grasses as well as *M. nodiflorium.* There were only 4 native marsh species found at this site (table 2).

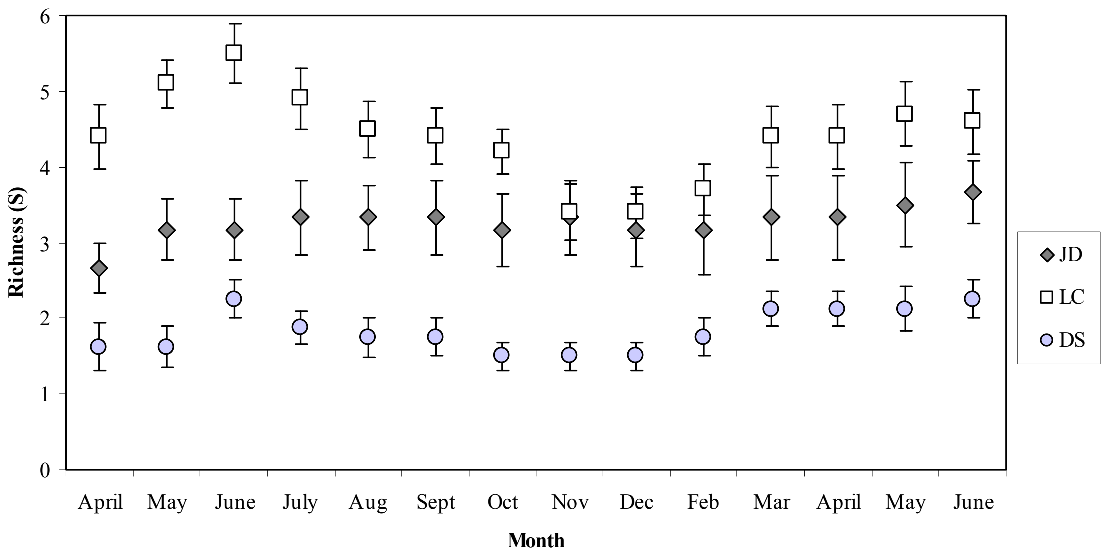

FIGURE 3. Plant species richness (mean ± *S.E.*) of the high marsh from April 2004 to June 2005 at a 5 year-old constructed marsh (JD; $n = 6$), a natural marsh (LC; $n = 10$), and a degraded marsh (DS; $n = 8$). The 8 year-old constructed marsh (GS) was not included because it does not contain high marsh habitat.

Vegetative species richness was highest at the natural marsh (LC) followed by the 5 year-old marsh (JD), with the degraded marsh (DS) having the lowest species richness (Tukey-Kramer, $p < 0.05$; figure 3). However, in October, November, and December 2004, there was no difference in richness between the natural marsh (LC) and the 5 year-old marsh (JD; Tukey-Kramer $p > 0.05$). The species richness at the natural marsh (LC) was significantly lower in November and December than in all other months except February (Tukey-Kramer, $p < 0.05$). At the 5 year-old marsh (JD), the number of species in May and June 2005 was significantly higher than it was in April 2004 (Tukey-Kramer, $p < 0.05$). Species richness at the degraded marsh (DS) was significantly lower in October, November, and December than in June and July 2004 as well as March, April, May, and June 2005 (Tukey-Kramer, $p < 0.05$).

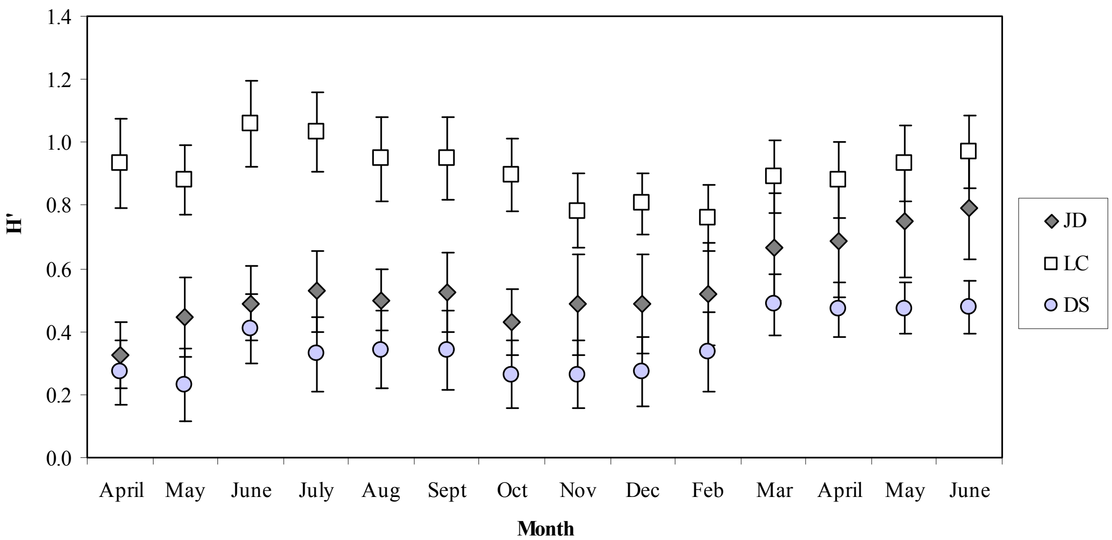

FIGURE 4. Plant species diversity (mean ± *S.E.*) of the high marsh from April 2004 to June 2005 at a 5 year-old constructed marsh (JD; $n = 6$), a natural marsh (LC; $n = 10$), and a degraded marsh (DS; $n = 8$). The 8 year-old constructed marsh (GS) was not included, because it does not contain high marsh habitat.

At the start of the study, there was no difference in diversity between the 5 year-old marsh (JD) and the degraded marsh (DS), with both having lower diversity than the natural marsh (Tukey-Kramer $p < 0.05$; figure 4). However, there was a significant change in species diversity over time at the 5 year-old marsh (JD; Tukey-Kramer, $p < 0.05$). In April 2004 species diversity was 0.3 ± 0.1 and by June 2005 it had increased to 0.8 ± 0.2. Thus, by the end of the study there was no difference in diversity between the natural marsh (LC) and the 5 year-old marsh (JD). There was a seasonal change in species diversity at the natural marsh (LC) with November, December, and February being lower than June and July 2004 (Tukey-Kramer, $p < 0.05$). However, this difference was not seen when compared to June 2005 (Tukey-Kramer, $p > 0.05$). The degraded marsh (DS) showed an increase in species diversity in the spring of 2005 due to the increased number of upland grasses and exotic ice plant that germinated. However, this increase was not statistically significant (Tukey-Kramer, $p > 0.05$).

Mid Marsh Zone

The mid marsh % vegetative cover at the natural marsh (LC) and the 8 year-old marsh (GS) were not significantly different from each other. Both had higher coverage than the mid marsh zone of the 5 year-old marsh (JD), which was higher than the degraded marsh (DS; Tukey-Kramer, $p < 0.05$; figure 5). There was no significant change in vegetative cover over the 14 month study period at the natural marsh (LC), the 8 year-old marsh (GS), or the degraded marsh (DS).

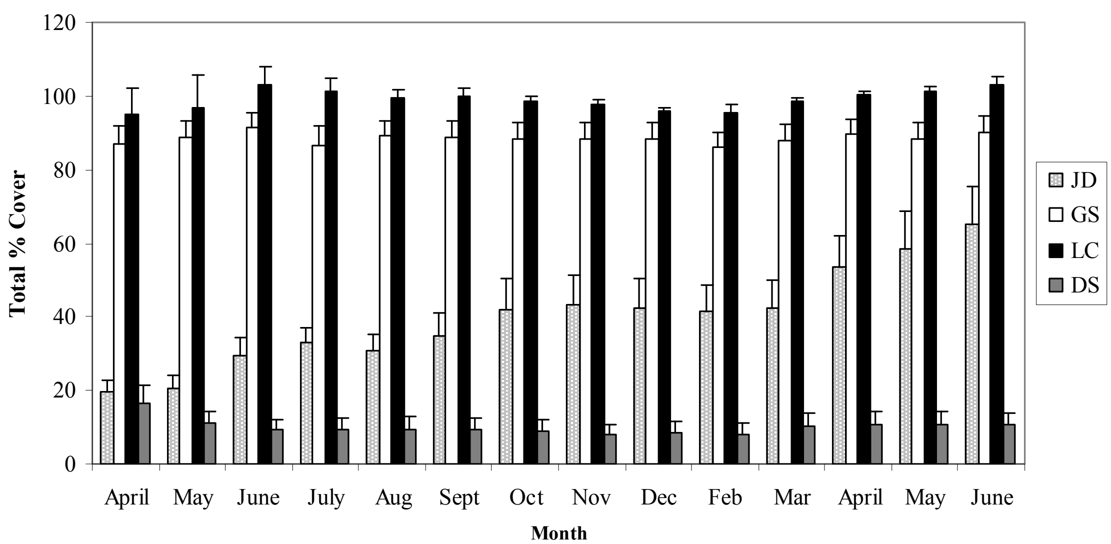

FIGURE 5. The vegetative cover (mean ± *S.E.*) from April 2004 to June 2005 in the mid marsh zone of the 5 year-old constructed marsh (JD; $n = 7$), 8 year-old constructed marsh (GS; $n = 26$), the natural marsh (LC; $n = 10$), and a degraded marsh (DS; $n = 12$).

TABLE 3. Species Found (*p* = Perennial, A = Annual) in the Mid Marsh at a 5 year-Old Constructed Marsh (JD), a 8 year-Old Constructed Marsh (GS), a Natural Marsh (LC) and a Degraded Marsh (DS) From April 2004 to June 2005.

Site	*Distichlis spicata*	*Salicornia subterminalis*	*Monathochloe litoralis*	*Cressa truxillensis*	*Salicornia virginica*	*Frankenia salina*	*Suaeda sp.*	*Limonium californicum*	*Jaumea carnosa*	*Batis maritima*	*Triglochin conicnna*	*Cuscuta salina*	*Salicornia bigelovii*	*Spartina foliosa*	Upland Grasses[a]	*Mesembryanthemum nodiflorium*[a]	**Cumulative species richness**
LC			P	A	P	P	P	P	P	P	A	A		P			11
GS					P	P		*	P	P				P			5
JD			P		P	P	P	P	P	P	*	*		P			8
DS		P		A	P										A	A	5

* Denotes a species that was present at the site but was rare and not found in any quadrats
[a] Denotes invasive species

The vegetative cover in the mid zone at the natural marsh (LC) ranged from 93.8% ± 4.2 to 104.4% ± 5.8. The vegetative cover at the 8 year-old marsh (GS) was relatively constant, ranging from 85.9 ± 4.3% to 91.2 ± 4.1% while the degraded marsh (DS) was consistently low and peaked at 16.6 ± 4.6%. The vegetative cover increased over time at the 5 year-old marsh (JD; Tukey-Kramer, $p < 0.05$). At this site, vegetative cover in April 2004 (19.3 ± 8.4%) was significantly lower than vegetative cover in June 2005 (65.1 ± 26.7%; Tukey-Kramer, $p < 0.05$). Despite this increase, vegetative cover at the 5 year-old site (JD) remained lower than the natural marsh (LC) or the 8 year-old marsh (GS) in June 2005 (Tukey-Kramer, $p < 0.05$). At the beginning of my study in April 2004, the vegetative cover at the 5 year-old marsh (JD) was not significantly different from that at the degraded marsh (DS; Tukey-Kramer, $p < 0.05$), and by June 2004 it was significantly higher than at the degraded marsh and remained higher through June 2005.

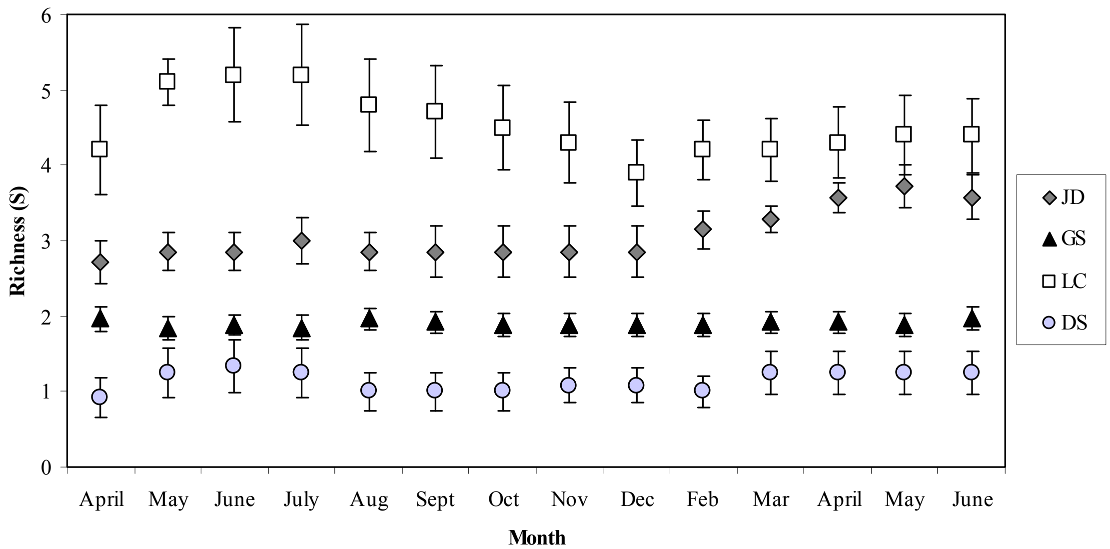

FIGURE 6. Species richness (mean ± *S.E.*) of the mid marsh zone from April 2004 to June 2005 at a 5 year-old constructed marsh (JD; $n = 7$), an 8 year-old constructed marsh (GS; $n = 26$), a natural marsh (LC; $n = 10$), and a degraded marsh (DS; $n = 12$).

There were a total of 11 plant species found in the mid marsh zone of the natural marsh (LC), 8 in the 5 year-old constructed marsh (JD), 5 in the 8 year-old constructed marsh (GS), and 5 in the degraded marsh (DS; table 3). There were no invasive species found in the natural marsh (LC) or either of the constructed marshes (JD and GS). The degraded marsh contained the invasive ice plant *Mesembryanthemum nodiflorium* in the mid marsh zone.

Mid marsh species richness was the highest at the natural marsh (LC) followed by the 5 year-old constructed marsh (JD), the 8 year-old constructed marsh (GS), and the degraded marsh (DS; Tukey-Kramer, $p < 0.05$; figure 6). There was no significant change in species richness over time at any site (Tukey-Kramer, $p > 0.05$). Although not significant, species richness at the 5 year-old marsh (JD) increased continually from April 2004 (2.71 ± 0.3) to June 2005 (3.57 ± 0.3) so that it was not significantly different from the natural marsh (LC) in May and June 2005.

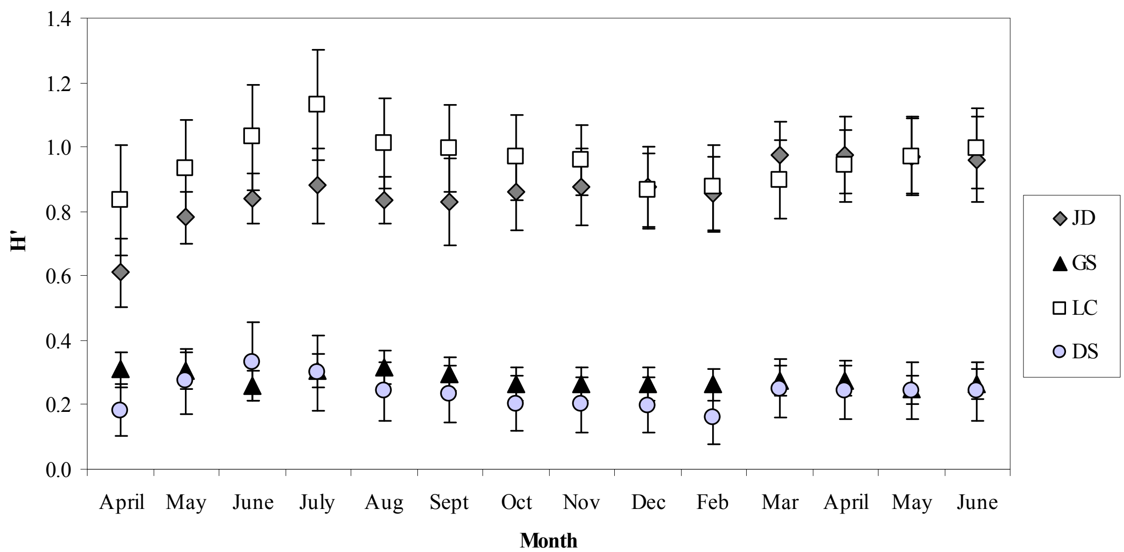

FIGURE 7. Species diversity (mean ± *S.E.*) of the mid marsh zone from April 2004 to June 2005 at a 5 year-old constructed marsh (JD; $n = 7$), an 8 year-old constructed marsh (GS; $n = 26$), a natural marsh (LC; $n = 10$), and a degraded marsh (DS; $n = 12$).

There was no significant difference in the species diversity between the natural marsh (LC) and the 5 year-old constructed marsh (JD; Tukey-Kramer, $p < 0.05$; figure 7). There was also no significant difference in species diversity between the degraded marsh (DS) and the 8 year-old constructed marsh (GS; Tukey-Kramer, $p < 0.05$). Both the 5 year-old marsh (JD) and the natural marsh (LC) had a higher species diversity than the 8 year-old marsh (GS) or the degraded marsh (DS; Tukey-Kramer, $p < 0.05$). There was no significant change in species diversity over time at any site despite the apparent seasonal differences at LC and DS (Tukey-Kramer, $p > 0.05$). However, species diversity at these sites was slightly higher in the summer when annuals were present and lower in the winter.

Low Marsh Zone

Percent vegetative cover was not significantly different between the natural marsh (LC) and the 8 year-old constructed marsh (GS; Tukey-Kramer, $p > 0.05$; figure 8). At the start of the study in April 2004, the vegetative cover at the 5 year-old constructed site (JD) was significantly lower than either the natural marsh (LC) or the 8 year-old marsh (GS; Tukey-Kramer, $p < 0.05$). By August 2004 the cover at the 5 year-old marsh (JD)

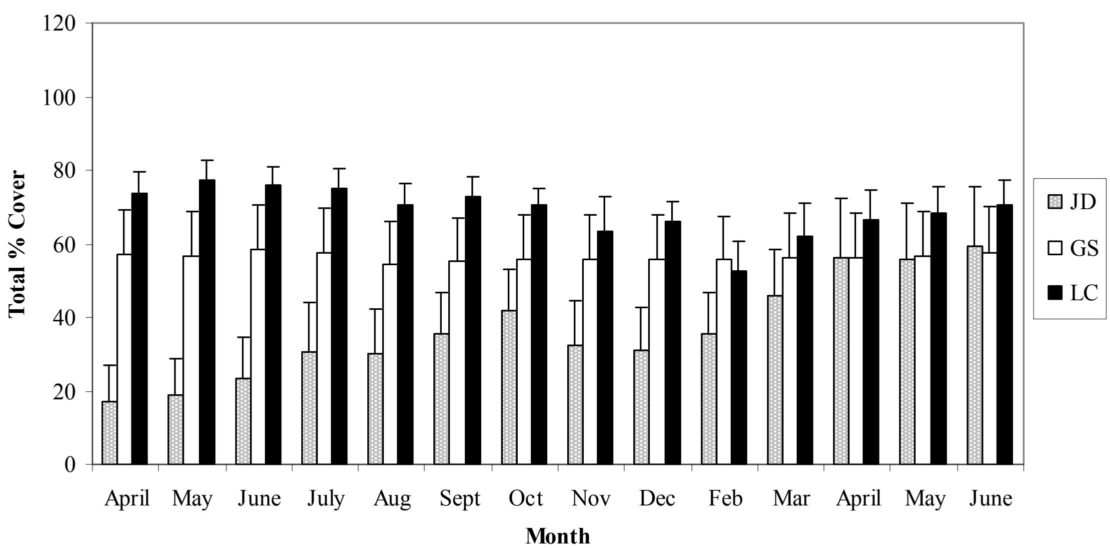

FIGURE 8. The vegetative cover (mean ± *S.E.*) from April 2004 to June 2005 in the low marsh zone of the four year-old constructed marsh (JD; $n = 6$), the 8 year-old constructed marsh (GS; $n = 14$), and the natural marsh (LC; $n = 10$). The degraded marsh (DS) was not included because it does not contain low marsh habitat.

was not significantly different from the 8 year-old marsh (GS) and by February 2005 the cover at the 5 year-old marsh (JD) was not significantly different from the natural marsh (LC; Tukey-Kramer, $p > 0.05$). During the 14 month study the vegetative cover at the 5 year-old site (JD) increased significantly from 17.7 ± 9.7% to 59.3 ± 16.3% (Tukey-Kramer, $p < 0.05$). The vegetative cover at the natural marsh (LC) dropped in the winter and was significantly lower in February than at the start or end of the study (Tukey-Kramer, $p < 0.05$). There was no significant change in the vegetative cover at the 8 year-old marsh (GS), which ranged from 55.1 ± 11.7% to 58.3 ± 12.4%.

TABLE 4. Plant Species *(p* = Perennial, A = Annual) Found in the Low Marsh at a 5 year-Old Constructed Marsh (JD), a 8 year-Old Constructed Marsh (GS), a Natural Marsh (LC) and a Degraded Marsh (DS) From April 2004 to June 2005. DS Does Not Contain Low Marsh Habitat.

Site	*Distichlis spicata*	*Salicornia subterminalis*	*Monathochloe litoralis*	*Cressa truxillensis*	*Salicornia virginica*	*Frankenia salina*	*Suaeda sp.*	*Limonium californicum*	*Jaumea carnosa*	*Batis maritima*	*Triglochin conicnna*	*Cuscuta salina*	*Salicornia bigelovii*	*Spartina foliosa*	Upland Grasses[a]	*Mesembryanthemum nodiflorium*[a]	Cumulative species richness
JD														P			1
GS					P				P	P				P			4
LC					P					P			A	P			4

a Denotes invasive species

There were a total of 4 species in the low marsh zone of both the natural marsh (LC) and the 8 year-old constructed site (GS), while there was only 1 species at the 5 year-old constructed site (JD; table 4). The single species found at JD was *Spartina foliosa*. This plant was the dominant low marsh species at the natural marsh (LC) and the 8 year-old marsh (GS). The other species at these two sites occurred sparingly in the low marsh with *S. foliosa* comprising over 90% of the plant cover. There were no invasive plant species found in the low marsh zone at any of the 3 sites.

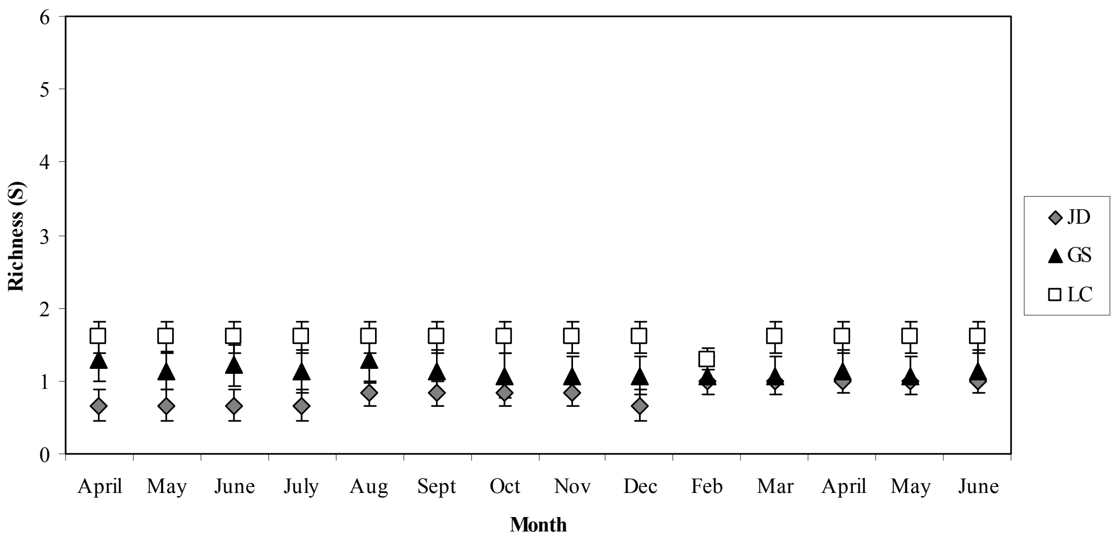

FIGURE 9. Plant species richness (mean ± *S.E.*) of the low marsh zone from April 2004 to June 2005 at a 5 year-old constructed marsh (JD; *n* = 6), an 8 year-old constructed marsh (GS; *n* =14), and a natural marsh (LC; *n* = 10). The degraded marsh (DS) was not included because it does not contain low marsh habitat.

Plant species richness was highest at the natural marsh (LC), followed by the 8 year-old constructed marsh (GS) and the 5 year-old constructed marsh (JD; figure 9). Because *Spartina foliosa* was the only species found in the low marsh at JD, there was no variance among the species present in the low zone. Thus, species richness and species diversity could not be tested statistically. Species richness was slightly higher in the

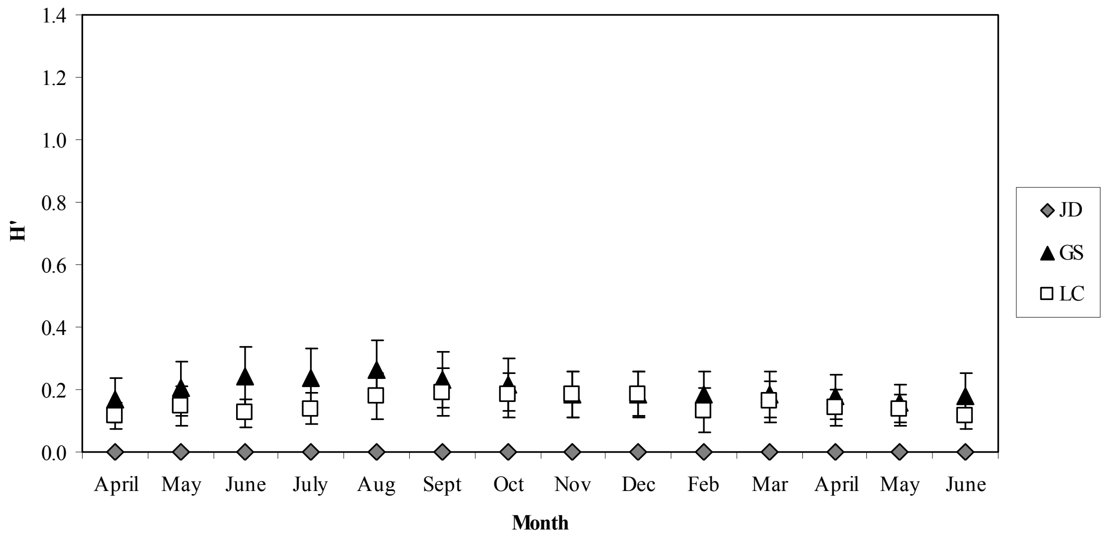

FIGURE 10. Plant species diversity (mean ± *S.E.*) of the low marsh from April 2004 to June 2005 at a 5 year-old constructed marsh (JD; *n* = 6), an 8 year-old constructed marsh (GS; *n* = 14), and a natural marsh (LC; *n* =10). The degraded marsh (DS) was not included because it does not contain low marsh habitat.

summer at both the natural marsh (LC) and the 8 year-old marsh (GS). Richness ranged from 1.3 ± 0.5 to 1.6 ± 0.7 at the natural marsh (LC) and from 1.1 ± 1.0 to 1.3 ± 1.1 at the 8 year-old marsh (GS). Because *S. foliosa* was the only plant species in the low marsh at the 5 year-old marsh (JD), average species richness leveled off at 1 after every quadrat contained plant cover (figure 9). Species diversity was similar at the natural marsh (LC) and the 8 year-old marsh (GS) ranging from 0.1 ± 0.04 to 0.12 ± 0.2 and 0.2 ± 0.1 to 0.3 ± 0.1, respectively (figure 10). Average species diversity remained at 0 throughout the study at the 5 year-old marsh (JD) due to the monospecific stand of *S. foliosa.*

Intra-Marsh Comparisons

Jack Dunster. The vegetative cover in the high marsh was relatively high at the beginning of the study in April 2004 (54.8 ± 13.4%) and did not significantly increase over the next 14 months (Tukey-Kramer, $p < 0.05$; figure 11). Conversely, the mid and low marsh zones initially had a much lower cover (19.6 ± 3.2% and 17.2 ± 9.7%, respectively), and increased significantly over time (Tukey-Kramer, $p < 0.05$). The vegetative cover in the high marsh was significantly higher than either the mid or low marsh in April 2004 (Tukey-Kramer, $p < 0.05$). There was no significant difference in the vegetative cover between the low and mid marsh throughout the study (Tukey-Kramer, $p > 0.05$). By February 2005 there was no significant difference in the cover among the 3 zones (Tukey-Kramer, $p > 0.05$). All zones had high variance due to the patchy nature of the plants at this site. In any given month, cover ranged from less than 10% to 100% cover.

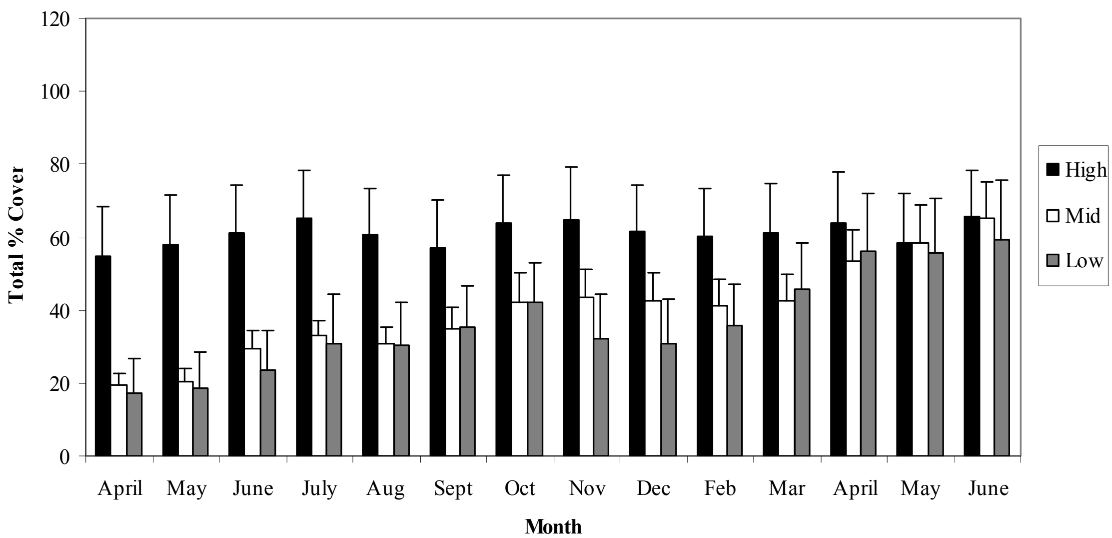

FIGURE 11. The vegetative cover (mean ± *S.E.*; $n = 6$) from April 2004 to June 2005 at the 5 year-old constructed marsh Jack Dunster.

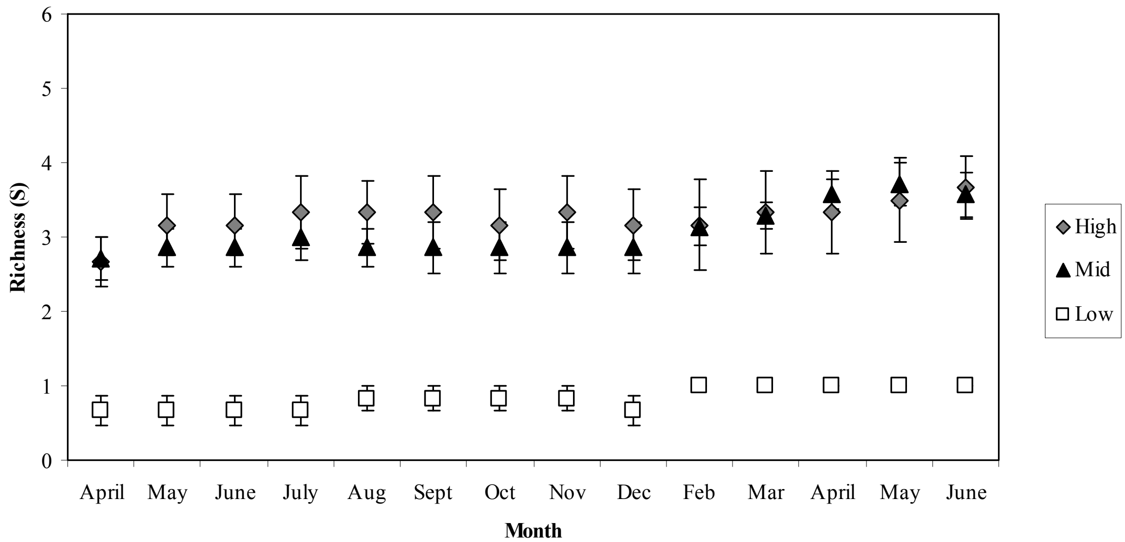

FIGURE 12. Species richness (mean ± *S.E.*; *n* = 6) of the high, mid, and low zones at the 5 year-old constructed marsh Jack Dunster from April 2004 to June 2005.

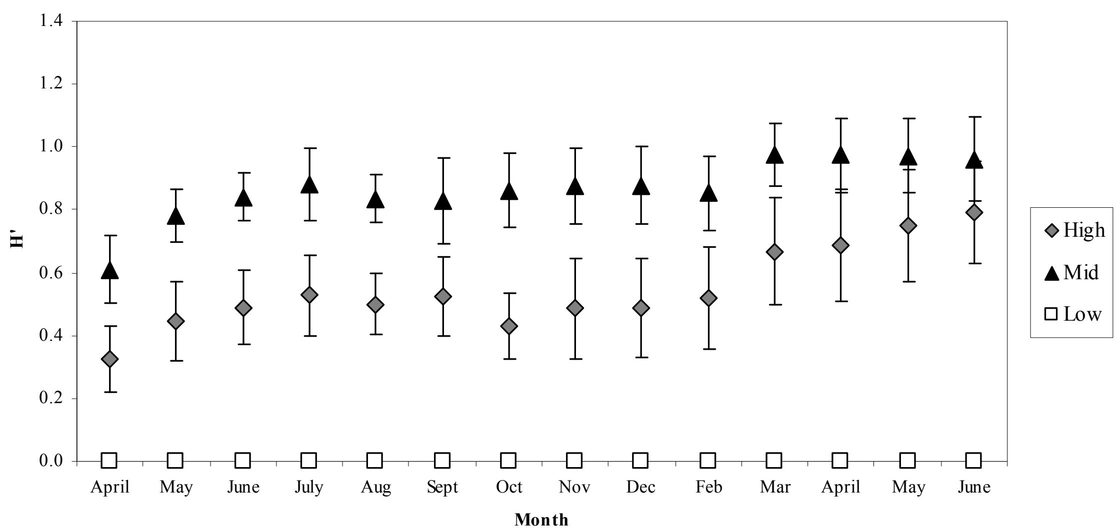

FIGURE 13. Species diversity (mean ± *S.E.*; *n* = 6) of the high, mid, and low marsh zones from April 2004 to June 2005 at the 5 year-old constructed marsh Jack Dunster.

At the 5 year-old site, species richness was significantly higher in the mid marsh zone than the high marsh zone from April 2004 to April 2005 (JD; Tukey-Kramer, $p <$

0.05; figure 12). The richness increased significantly from April 2004 (0.3 ± 0.1) to June 2005 (0.8 ± 0.2) in the high marsh zone (Tukey-Kramer, $p < 0.05$), while there was no significant change in richness in the mid marsh zone (Tukey-Kramer, $p > 0.05$). There was no difference in richness between the 2 zones in May and June 2005. Richness in the low marsh zone remained low throughout the study because *Spartina foliosa* was the only plant species present. As a result, no statistical analyses could be performed with the low marsh data. There were no new native species present throughout the study that were not initially planted during the construction of this site.

The species diversity in the mid marsh zone was significantly higher than the high marsh zone in April 2004 (Tukey-Kramer, $p < 0.05$; figure 13). By March 2005, species diversity was significantly higher than April 2004 in the high marsh zone and remained so throughout the remainder of the study (Tukey-Kramer, $p < 0.05$). By the end of the study in June 2005, there was no difference in species diversity between the mid and high zones (Tukey-Kramer, $p > 0.05$). Species diversity remained at 0 throughout the study in the low marsh zone because there was only one species present.

<u>Golden Shores</u>. At the beginning of the study in April 2004 the percent cover in the mid marsh zone was 87.1 ± 4.6% and in June to 2005 the cover had increased slightly, but not significantly, to 90.2 ± 4.2% (Tukey-Kramer, $p > 0.05$; figure 14). The vegetative cover in the low marsh zone was 57.3 ± 12.1% in April 2004 and did not change significantly over the 14 month study (Tukey-Kramer, $p > 0.05$). Cover in the mid marsh zone was significantly higher than the low marsh zone throughout the study (Tukey-Kramer, $p < 0.05$).

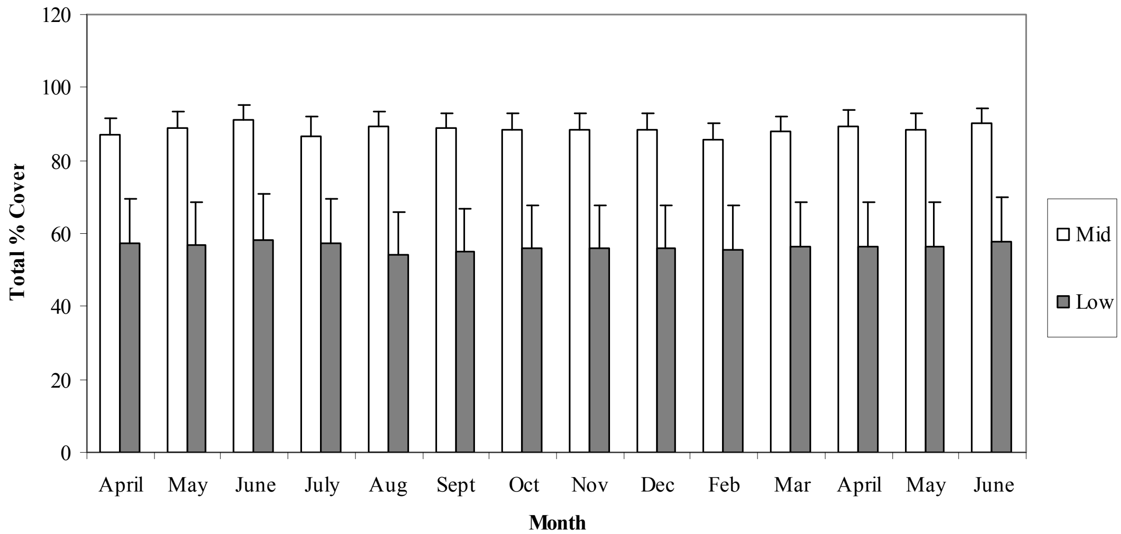

FIGURE 14. The vegetative cover (mean ± *S.E.*) in mid (n = 26) and low (n = 14) marsh zones from April 2004 to June 2005 at the 8 year-old constructed marsh Golden Shores.

Richness in the mid marsh zone ranged from 1.9 ± 0.2 to 2.0 ± 0.9 while the low marsh zone ranged from 1.1 ± 0.3 to 1.3 ± 0.3 (figure 15). The species richness was significantly higher in the mid marsh zone than the low marsh zone throughout the study (Tukey-Kramer, $p < 0.05$). Neither zone had any change in richness during the 14 month study (Tukey-Kramer, $p > 0.05$). There were no species observed in either zone that were not initially planted during the mitigation term.

Species diversity of the mid marsh zone ranged from 0.2 ± 0.2 to 0.3 ± 0.1 while the low marsh ranged from 0.7 ± 0.1 to 0.3 ± 0.1 (figure 16). There was no difference in the species diversity between the mid and low marsh zones. There was no significant change in species diversity in the mid or low marsh zone during the 14 month study (Tukey-Kramer, $p > 0.05$).

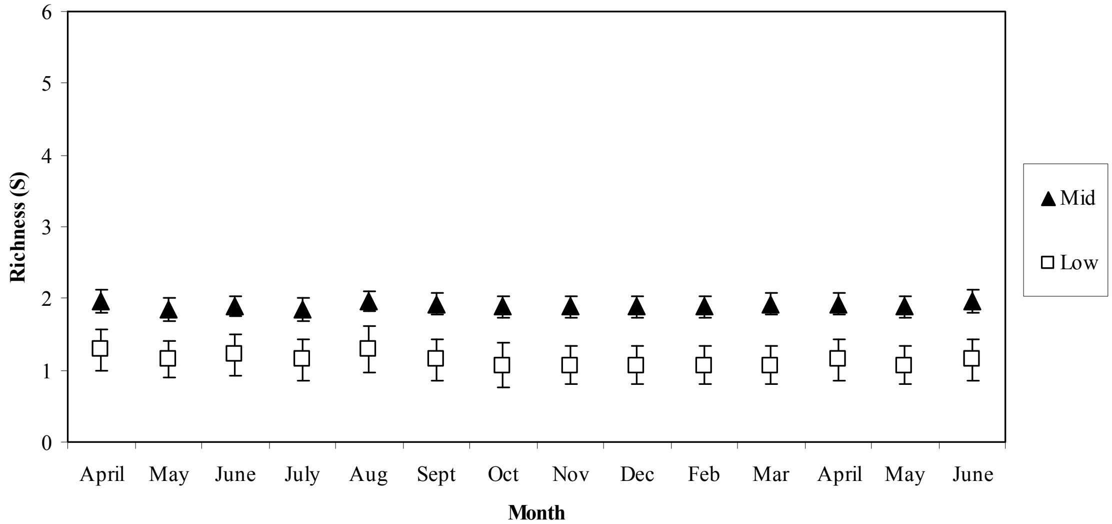

FIGURE 15. Species richness (mean ± *S.E.*) of the mid (n = 26) and low (n = 14) zones at the 8 year-old constructed marsh Golden Shores from April 2004 to June 2005.

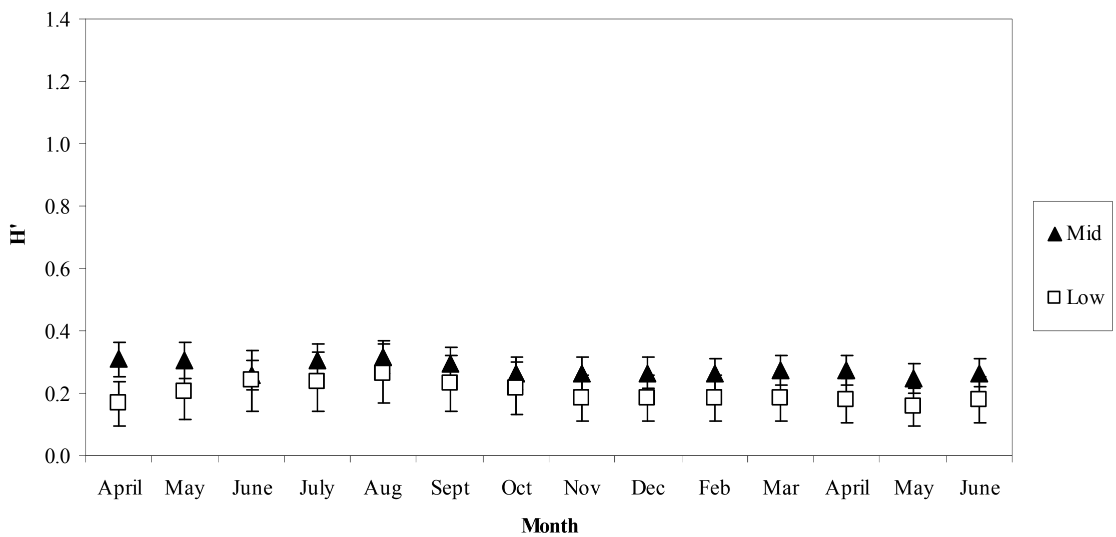

FIGURE 16. Species diversity (mean ± *S.E.*) of the mid (n = 26) and low (n = 14) marsh zones from April 2004 to June 2005 at the 8 year-old constructed marsh Golden Shores.

Seed Bank Dynamics

Few seedlings germinated from any of the cores. There were a total of 44 seedlings observed in all of the cores combined. Due to the low amount of germination no statistical analyses were run on the data. The majority of the seedlings germinated from the high marsh cores at the natural marsh (LC; 16) and the degraded marsh (DS; 17). In the high marsh there was a total of 5 species that germinated from the natural marsh (LC), only one of which was an invasive (table 5). At the degraded marsh (DS) all species that germinated in the high marsh were either the invasive ice plant *Mesembryanthemum nodiflorium* or upland grasses. While no seedlings were observed in the cores from the 5 year-old marsh (JD) there were a few (<10) seedlings of *M. nodiflorium* observed in the field.

TABLE 5. Seedlings That Germinated From the High Marsh Cores (n = 20) Taken From the 5 Year-Old Constructed Marsh (JD), the Natural Marsh (LC), and the Degraded Marsh (DS) in October 2004 and March 2005. Note that the 8 Year-Old Marsh (GS) Does Not Contain High Marsh Habitat.

Site	*Distichlis spicata*	*Monathochloe litoralis*	*Cressa truxillensis*	*Salicornia sp*	*Frankenia salina*	*Suaeda sp.*	*Limonium californicum*	*Jaumea carnosa*	*Batis maritima*	*Triglochin conicnna*	*Cuscuta salina*	*Spartina foliosa*	Upland Grasses[a]	*Mesembryanthemum nodiflorium*[a]	Total # of seedlings germinated
JD														*	0
LC	2			11	1	1							1		16
DS													2	15	17

a Denotes invasive species
* Denotes seedlings seen in the field but not in the cores

TABLE 6. Seedlings That Grew From the Mid Marsh Cores (n = 20) Taken From the 5 Year-Old Constructed Marsh (JD), the 8 Year-Old Constructed Marsh (GS), the Natural Marsh (LC), and the Degraded Marsh (DS) in October 2004 and March 2005.

Site	*Distichlis spicata*	*Monathochloe litoralis*	*Cressa truxillensis*	*Salicornia sp*	*Frankenia salina*	*Suaeda sp.*	*Limonium californicum*	*Jaumea carnosa*	*Batis maritima*	*Triglochin conicnna*	*Cuscuta salina*	*Spartina foliosa*	Upland Grasses	*Mesembryanthemum nodiflorium*	**T**otal # of seedlings germinated
JD				1		*						*			1
GS				2											2
LC				5		1									6
DS				1											1

a Denotes invasive species
* Denotes seedlings observed in the field but not seen in the cores

The mid marsh zone had the second most seedlings with 10 (table 6). Six seedlings germinated from the natural marsh (LC), representing *Salicornia* sp. and *Suaeda* sp. (table 6). There was 1 seedling from the 5 year-old marsh (JD), 2 from the 8 year-old marsh (GS) and 1 from the degraded marsh (DS) all of which were *Salicornia* sp. (table 6). Seedlings from 2 additional species (*Suaeda* sp. and *Spartina foliosa*) were observed in the field at the 5 year-old marsh (JD). However, there were fewer than 5 seedlings observed for each species.

TABLE 7. Seedlings Observed in the Low Marsh Cores (n = 20) Taken From the 5 Year-Old Constructed Marsh (JD), the 8 Year-Old Constructed Marsh (GS), and the Natural marsh (LC) in October 2004 and March 2005. Note that the Degraded Marsh (DS) Does Not Contain High Marsh Habitat.

Site	*Distichlis spicata*	*Monathochloe litoralis*	*Cressa truxillensis*	*Salicornia sp*	*Frankenia salina*	*Suaeda sp.*	*Limonium californicum*	*Jaumea carnosa*	*Batis maritima*	*Triglochin conicnna*	*Cuscuta salina*	*Spartina foliosa*	Upland Grasses[a]	*Mesembryanthemum nodiflorium*[a]	Total # of seedlings germinated
JD															0
GS								1				1			2
LC				1											1

a Denotes invasive species

The low marsh had the lowest number of seedlings (table 7). There were 2 seedlings from the 8 year-old marsh (GS) representing *Spartina foliosa* and *Jaumea carnosa* and one seedling from the natural marsh (LC) representing the genus *Salicornia* (table 7). No seedlings grew from the cores collected or were observed in the field from the low zone at the 5 year-old marsh (JD).

<u>Sediment Characteristics</u>

Sediment organic content differed significantly by site ($p < 0.001$), zone ($p < 0.001$), and depth ($p < 0.001$). Organic content did not vary with time of year and thus, the data were pooled over month prior to statistical analysis. In addition, there were significant interactions between the effects of site and zone ($p < 0.001$), zone and depth ($p < 0.01$), as well as depth and site ($p < 0.01$).

Grain size fractions were examined by combing the clay and silt fractions to determine a mud fraction percentage, which was tested statistically. Data were pooled across month because % mud did not vary over time of year ($p > 0.05$). Percent mud varied among site ($p < 0.001$) and zone ($p < 0.001$) but not depth ($p > 0.05$). In addition, there was a significant interaction between the effects of marsh zone and site ($p < 0.001$), zone and depth ($p < 0.01$), as well as site and depth (p< 0.01). Data were not pooled across depth because of the significant depth interactions. In addition to % mud, the mode grain size was examined. Mode did not differ over time of year, which allowed the data to be pooled across month. Grain size mode varied among site ($p < 0.001$) and zone ($p < 0.001$) but not depth ($p > 0.05$). There was a significant interaction between the effects of marsh site and zone ($p <0.001$).

Due to the significant interactions for organic content, % mud, and grain size mode, Tukey tests were used to make specific comparisons among group means.

<u>High Marsh Zone</u>

Organic content at the natural marsh (LC) ranged from 5.6 ± 0.4% to 6.6 ± 0.3% (mean ± S.E.) and did not differ from the degraded marsh (DS) which ranged from 5.4 ± 0.4% to 6.1 ± 0.4% (Tukey, $p < 0.05$; figure 17). Organic content at 5 year-old constructed marsh (JD) was significantly lower than either the natural marsh (LC) or the degraded marsh (DS; Tukey, $p < 0.05$) and ranged from 3.0% ± 0.3 to 3.5% ± 0.3. There was no significant difference over depth at any site (Tukey, $p > 0.05$).

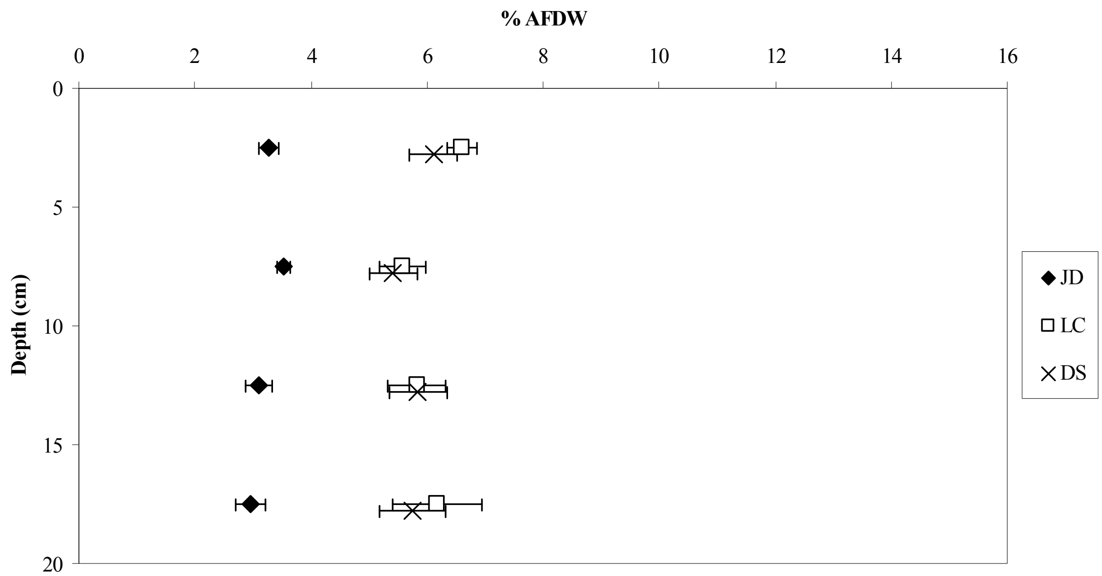

FIGURE 17. Organic content (% AFDW; mean ± *S.E.*) of sediment cores taken from the high marsh in October 2004 and May 2005 at a 5 year-old constructed marsh (JD), a natural marsh (LC), and a degraded marsh (DS). Data points represent a 5cm section of the core not a specific depth point in the core (i.e., data points at 2.5cm represent sediment from 0-5cm). The 8 year-old marsh (GS) does not contain high marsh habitat.

The 5 year-old marsh (JD) had a lower % mud than either the natural marsh (LC) or the degraded marsh (DS; Tukey, $p < 0.05$; figure 18). There was no difference in % mud between the natural marsh (LC) and the degraded marsh (DS; Tukey $p > 0.05$). There was a significantly lower % mud in the 0-5cm depth interval (51.7 ± 2.1%) than all other depth ranges at the 5 year-old marsh (JD; Tukey, $p < 0.05$). There was no change in % mud over depth at the natural marsh (LC) or the degraded marsh (DS).

Grain size mode at the 5 year-old constructed marsh (JD) ranged from 113.3 ± 3.9µm to 126.1 ± 4.4µm and was significantly higher than either the natural marsh (LC) or the degraded marsh (DS; Tukey, $p < 0.05$; figure 19). The grain size mode at the natural marsh (LC) ranged from 27.8 ± 4.2µm to 35.1µm ± 11.0µm and was not

significantly different from the degraded site, which ranged from 52.5 ± 21.7μm to 55.5 ± 22.8μm (Tukey, $p > 0.05$). There were no significant changes in grain size mode over depth at any site.

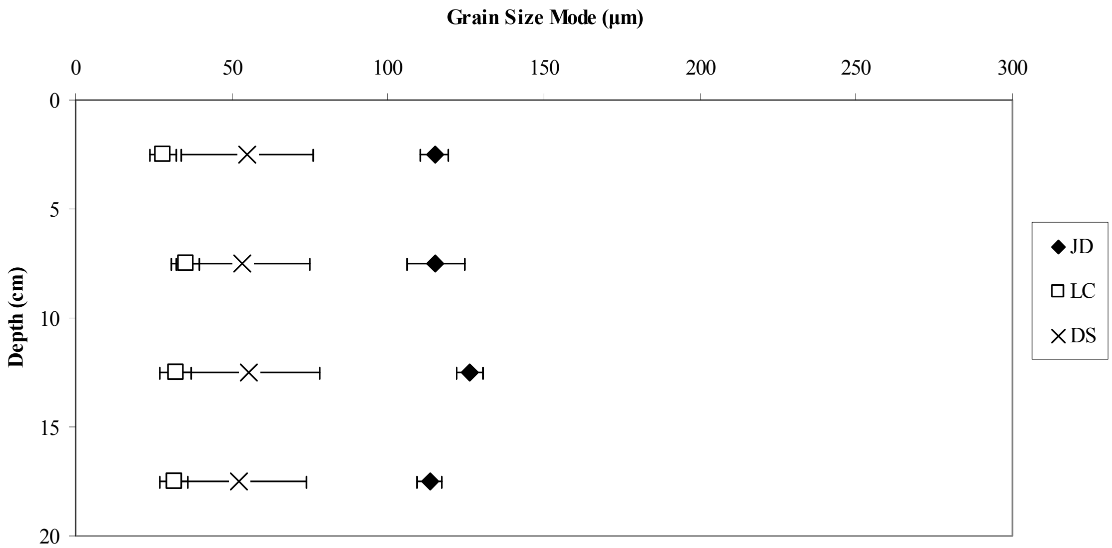

FIGURE 19. Grain size mode (mean ± *S.E.*) of sediment cores taken from the high marsh in October 2004 and May 2005 at a 5 year-old constructed marsh (JD), a natural marsh (LC), and a degraded marsh (DS). Data points represent a 5cm section of the core not a specific depth point in the core (i.e., data points at 2.5cm represent sediment from 0-5cm). The 8 year-old marsh does not contain high marsh habitat.

<u>Mid Marsh Zone</u>

There was no significant difference in organic content between the 5 year-old constructed marsh (JD) and the 8 year-old constructed marsh (GS; Tukey, $p > 0.05$; figure 20). Organic content at the 5 year-old marsh ranged from 2.5 ± 0.2% to 3.1 ± 0.2% while at the 8 year-old marsh it ranged from 1.8 ± 0.3% to 2.6 ± 0.3%. There was no significant difference over depth at either site (Tukey, $p > 0.05$). Organic content at both constructed marshes was significantly lower than the natural marsh (LC), which was lower than the degraded marsh (DS; Tukey, $p < 0.05$). There was no difference over depth at the degraded marsh (DS; Tukey, $p > 0.05$). However, at the natural marsh (LC), organic content was significantly higher in the 0-5cm depth range (14.0 ± 0.5%) than the 10-15cm (8.9 ± 0.8%) and the 15-20 cm depth ranges (7.5 ± 0.3%; Tukey, $p < 0.05$).

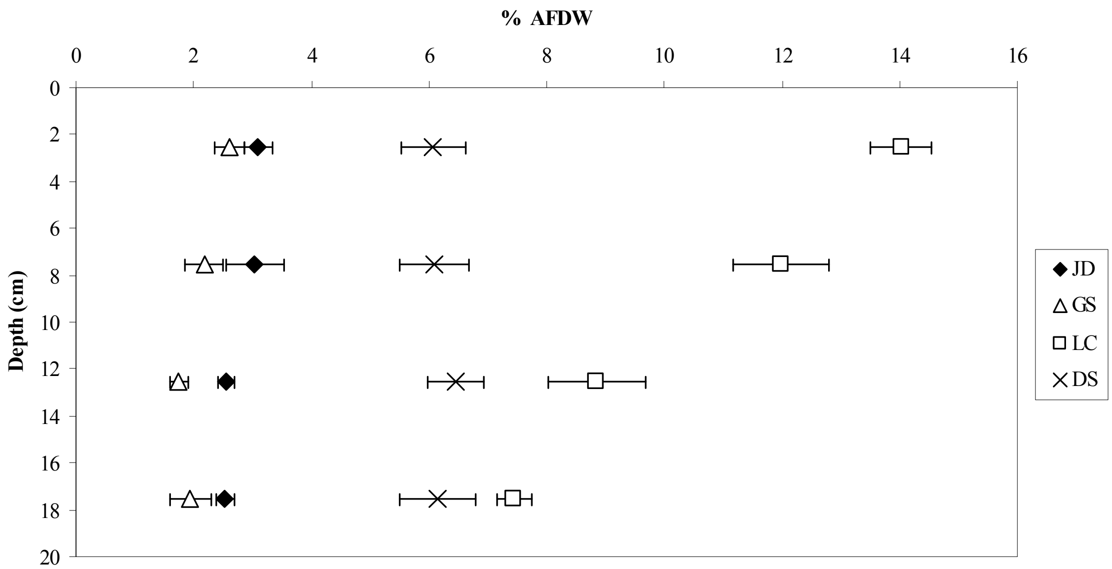

FIGURE 20. Percent ash-free dry weight (% AFDW) of sediment cores taken from the mid marsh zone in October 2004 and May 2005 at a 5 year-old constructed marsh (JD), a 8 year-old constructed marsh (GS), a natural marsh (LC), and a degraded marsh (DS). Data points represent a 5cm section of the core, not a specific depth point in the core (i.e., data points at 2.5cm represent sediment from 0-5cm).

The 5 year-old constructed marsh (JD) had a higher sediment mud fraction than the 8 year-old marsh (GS; Tukey, $p < 0.05$; figure 21). There was no difference in % mud among depths at either site (Tukey, $p > 0.05$). Percent mud at the 5 year-old marsh ranged from 52.4 ± 2.8% to 55.9 ± 0.9%, while the 8 year-old site ranged from 32.7 ± 2.9% to 37.5 ± 1.9%. Percent mud at both constructed marshes was lower than either the natural marsh (LC) or the degraded marsh (DS; Tukey, $p < 0.05$). There was no difference between the natural marsh (LC) and the degraded marsh (DS; Tukey, $p >$

0.05). There was no difference over depth at the natural site (LC; Tukey, $p > 0.05$). However, at the degraded marsh (DS) the 0-5 cm depth interval (73.6 ± 4.0%) had a smaller mud fraction than the 10-15 cm and 15-20cm depth intervals (83.6 ± 4.9% and 83.4 ± 4.7%, respectively Tukey, $p < 0.05$).

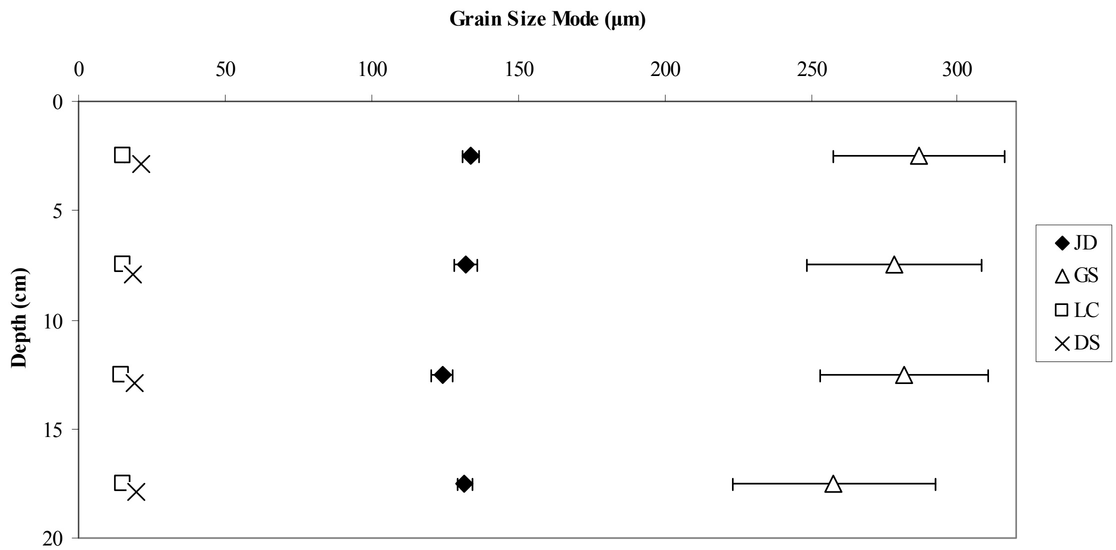

FIGURE 22. Grain size mode (mean ± *S.E.*) of sediment cores taken from the mid marsh in October 2004 and May 2005 at a 5 year-old constructed marsh (JD), 8 year-old constructed marsh (GS), a natural marsh (LC), and a degraded marsh (DS). Data points represent a 5 cm section of the core, not a specific depth point in the core (i.e., data points at 2.5 cm represent sediment from 0-5 cm).

Grain size mode at the 8 year-old marsh (GS) ranged from 257.8 ± 34.7µm to 286.8 ± 29.4µm and was higher than the 5 year-old marsh (JD), which ranged from 124.0 ± 3.6µm to 133.9 ± 2.6µm (Tukey $p < 0.05$; figure 21). Both constructed marshes were significantly higher than the natural marsh (LC) and the degraded marsh (DS; Tukey $p < 0.05$). There was no difference in the grain size mode between the natural marsh (LC) and the degraded marsh (DS). Grain size mode did not change significantly over depth at any site (Tukey $p > 0.05$).

Low Marsh Zone

There was no significant difference in organic content between the 5 year-old constructed marsh (JD) and the 8 year-old constructed marsh (GS). The natural marsh (LC) had a higher organic content than either of the constructed sites (Tukey, $p < 0.05$). There was no difference in organic content over depth at either of the constructed marshes (Tukey, $p > 0.05$). The 0-5 cm depth range at the natural marsh (LC) had an organic content of 13.9 ± 0.6%, which was significantly higher than all other depth ranges (Tukey, $p < 0.05$).

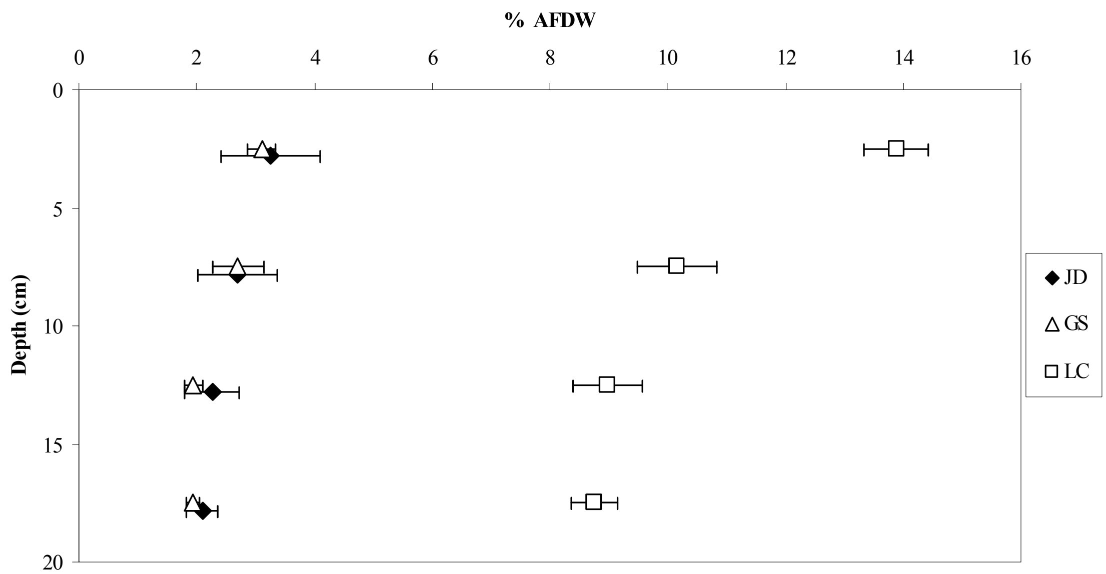

FIGURE 23. Percent ash-free dry weight (% AFDW) of sediment cores taken from the low marsh zone in October 2004 and May 2005 at a 5 year-old constructed marsh (JD), a 8 year-old constructed marsh (GS), and a natural marsh (LC). Data points represent a 5cm section of the core, not a specific depth point in the core (i.e., data points at 2.5cm represent sediment from 0-5cm). The degraded marsh (DS) does not contain low marsh habitat.

There was no difference in % mud between the 5 year-old marsh (JD) and the 8 year-old marsh (GS; Tukey, $p > 0.05$, figure 24). Percent mud at the 5 year-old site (JD)

ranged from 35.6 ± 0.8% to 39.2 ± 2.4%, while the 8 year-old site (GS) ranged from 33.7 ± 3.4% to 39.3 ± 4.2%. Percent mud at the natural marsh (LC) was higher than either of the constructed marshes (Tukey, $p < 0.05$) and ranged from 79.4 ± 1.1% to 81.8 ± 0.9%. There was no difference in % mud over depth at any site (Tukey, $p > 0.05$).

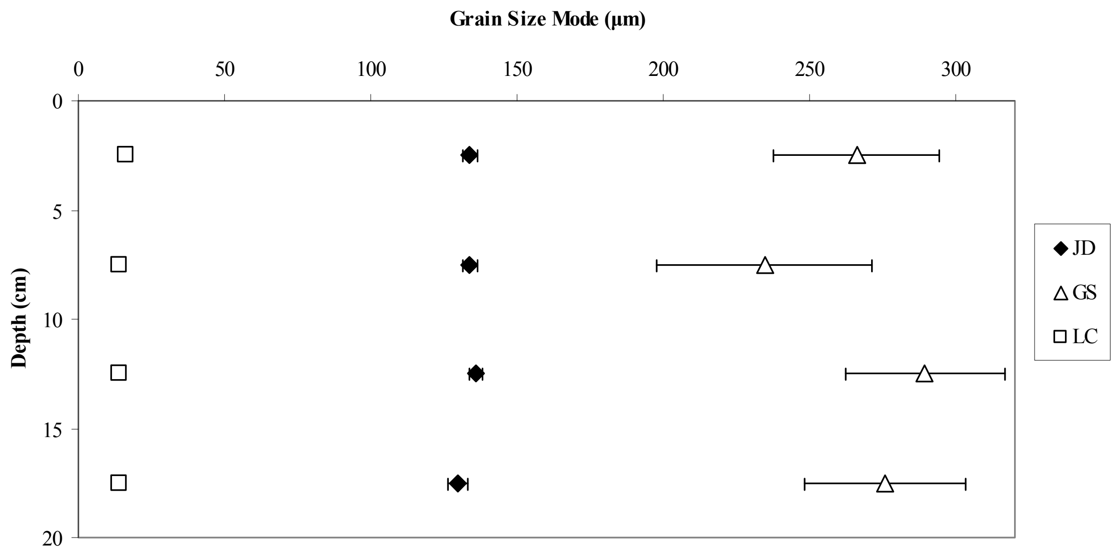

FIGURE 25. Grain size mode (mean ± *S.E.*) of sediment cores taken from the low marsh in October 2004 and May 2005 at a 5 year-old constructed marsh (JD), 8 year-old constructed marsh (GS), and a natural marsh (LC). Data points represent a 5cm section of the core, not a specific depth point in the core (i.e., data points at 2.5cm represent sediment from 0-5cm). Note that the degraded site (DS) does not contain low marsh habitat.

Grain size mode at the 8 year-old marsh (GS) was significantly higher than the 5 year-old constructed marsh (Tukey, $p < 0.05$; figure 24). Grain size mode ranged from 234.5 ± 36.7µm to 289.2 ± 27.2µm at the 8 year-old marsh (GS) while the 5 year-old marsh (JD) ranged from 129.8 ± 2.3µm to 135.9 ± 2.4µm. The natural marsh (LC) had a lower grain size mode than either of the constructed marshes (Tukey, $p < 0.05$), which ranged from 14.3 ± 0.3µm to 16.1 ± 0.6µm. There was no significant change in grain size mode over depth at any site (Tukey, $p > 0.05$).

Intra-Marsh Comparisons

Jack Dunster. Organic content ranged between 2% and 3% for all zones and was not significantly different among the high, mid, and low marsh zones at the 5 year-old marsh (JD; Tukey, $p > 0.05$). There was no difference in organic content over depth in any zone (Tukey, $p > 0.05$). There was no significant difference in sediment mud fraction between the mid and high marsh zones (Tukey, $p > 0.05$). However, % mud in the low marsh was lower than either the high or mid marsh (Tukey, $p < 0.05$). There was no change in % mud over depth in the mid and low marsh zones. Percent mud in the mid marsh ranged from 52.4 ± 2.8% to 55.9 ± 0.9%, while the low marsh ranged from 35.6 ± 0.8% to 39.2 ± 2.4%. There was a significantly lower % mud in the 0-5 cm depth range (51.7 ± 2.1%) than all other depth ranges in the high marsh zone.

There was no difference in grain size mode among the three zones and there was no change over depth in any zone (Tukey, $p > 0.05$). Grain size mode in the mid marsh ranged from 124.0 ± 3.6µm to 133.9 ± 2.6µm while the low ranged from 129.8 ± 2.3µm to 135.9 ± 2.4µm. The high marsh had a slightly lower grain size mode, ranging from 113.3 ± 3.9µm to 126.1 ± 4.4µm. However, the difference was not significant (Tukey, $p > 0.05$).

Golden Shores. There was no difference in organic sediment content between the mid and low marsh zones at the 8 year-old marsh (Tukey, $p > 0.05$). There was no difference in organic content over depth in either zone and in the mid marsh it ranged from 1.8 ± 0.3% to 2.6 ± 0.3%, while the low marsh ranged from 1.9 ± 0.2% to 3.1±

0.2%. There was no difference in sediment mud fraction between the mid and low marsh zones (Tukey, $p > 0.05$). There was no difference over depth in the mid marsh zone where the mud fraction ranged from 32.7 ± 2.9% to 37.5 ± 1.9% or the low marsh zone where it ranged from 33.7 ± 3.4% to 39.3 ± 4.2%.

There was no difference in grain size mode between zones or over depth (Tukey, $p > 0.05$). Grain size mode in the mid marsh ranged from 257.8 ± 34.7µm to 286.8 ± 29.4µm, while the low marsh zone ranged from 234.5 ± 36.7µm to 289.2 ± 27.2µm.

CHAPTER 4

DISCUSSION

Plant Community

The plant communities at the 2 constructed marshes developed differently over time with respect to cover and diversity. As hypothesized, the high and mid marsh zone vegetative cover at the 5 year-old constructed marsh (JD) remains below levels found at the natural marsh (LC). However, by the end of the study, plant cover levels in both zones at the 5 year-old marsh were higher than that found in the degraded marsh. The 5 year-old site low marsh vegetative cover was initially lower than at the natural marsh but by the end of the study no difference was present. Plant cover of the mid marsh zone at the 5 year-old site was lower than the 94 ± 6.4% reported for the 8 year-old site at 5 years post construction (Beck and Paquette 2003). This difference could be attributed to how the sites were planted. At the 8 year-old site plants were chosen based on how quickly they were expected to fill in the site. At the 5 year-old site, plant species were chosen to represent the vegetative composition of the nearby natural Los Cerritos marsh (Arkenstall, pers. comm.). This difference in planning was a result of different goals for the 2 sites. The 8 year-old site was a mitigation project and, therefore, the goal was to reach the specified cover in 5 years time. The goal for the 5 year-old site was to create a marsh which was representative of nearby natural marshes. Thus, it will likely take longer for the 5 year-old site to fill in.

Plant diversity at the 5 year-old site was variable among zones and higher than initially hypothesized in the high and mid marsh, with these zones having a similar diversity as the corresponding zones in the natural marsh while the low zone had lower diversity than the natural marsh. In all zones, plant species richness at the 5 year-old site remained lower than at the natural marsh throughout the study. However, species richness and diversity at the 5 year-old marsh greatly exceeded that found at the degraded marsh. Throughout the entire marsh, only 4 species of annuals were found in quadrats at the natural marsh that were not sampled at the 5 year-old marsh (*Cressa truxillensis, Triglochin concinna, Salicornia bigelovi,* and *Cuscuta salina*) and 2 of these (*T. concinna* and *C. salina*) were observed in isolated patches outside the quadrats in the 5 year-old marsh. The absence of annuals at the 5 year-old marsh can be attributed to the focus on perennials during the planting of the site. *T. concinna* was planted in select locations of the marsh but did not expand beyond these areas. The natural marsh showed increased richness and diversity in the spring and summer months when annuals were present. This seasonal pattern was lacking from the constructed marsh where annuals were missing. Annual plant cover is often low in constructed marshes because it is easier and more convenient to transplant perennial species from nearby natural marshes (Zedler 1996a). *Spartina foliosa* was the only, therefore dominant, plant in the low marsh zone at the 5 year-old marsh. This *Spartina* sp. is the dominant endemic in West Coast salt marshes, as was found at the natural marsh in this study (Zedler 1982). Thus, the vegetative community in the low marsh zone of the 5 year-old site is a reasonable representation of low marsh zones in southern California. Due to the large number of species that were planted in the high and mid zones at the 5 year-old marsh and the high survival rates of all species (>80%; Arkenstall pers. comm.), I expect that as species continue to spread, the average richness and diversity will increase.

Differences in vegetative cover, diversity, and richness among the zones at the 5 year-old marsh illustrate that different areas of the marsh are progressing at different rates. This can likely be attributed to differences in inundation as well as individual plant growth characteristics. All areas of the marsh were watered extensively for the first year, after which plants were only watered occasionally by hand due to widespread establishment of invasive plants. In the high marsh zone, where there is little inundation except during the highest tides, it is likely that the lack of water is negatively affecting plant growth due to the near absence of sediment pore water and the resulting high soil salinities. This could explain why vegetative cover in the high marsh did not increase during the 14 month study while it did in the mid and low marsh zones. Southern California received near record rainfall in the winter of 2004-2005. Contrary to expectations, vegetative cover in the high marsh of the 5 year-old site did not increase the following spring in response to these winter rains. The upper marsh is a more stressful environment for salt marsh plants than the lower elevations are and thus tend to fill in at a slower rate (Dawe et al 2000). Therefore, it is likely that it will take much longer for the higher marsh elevations to fill in at the 5 year-old site and monitoring should be continued to ensure that the plant community is developing properly.

Plant cover in the low marsh zone of the 5 year-old site showed the greatest increase over time. *Spartina foliosa* (the only species found in the low marsh at this site) has shown increased recruitment of new clones after winter rains decreased soil salinity (Zedler 1982). The heavy rainfall in the winter of 2004-2005 could account, in part, for the rapid expansion of *S. foliosa* seen in 2005. While plant cover in the mid marsh at the 5 year-old site remained below that found in the mid marsh at the natural marsh, it did increase dramatically over the 14 months of the study. If plant growth at the 5 year-old site continues at or near the current rate, cover in the mid marsh will likely reach levels near those at the natural marsh in the next few years.

In addition to the invasive species sampled in the high marsh at the 5 year-old site, there are other invasive plants along the upper fringes of the marsh and in the surrounding upland habitat that have the potential to invade the marsh. Overall, the invasive cover was low in the marsh itself as only 2 quadrats had invasive plants and these had less than 0.5% cover. The low level of invasives can be attributed to the continued weeding at this site. Unwanted plants were removed from the Reserve on a regular basis, both from the marsh and the surrounding upland habitat, prior to the start of the study; however, during the course of this study, invasives were not removed from the marsh itself (Arkenstall, pers. comm.). Newly restored sites have been more susceptible to invasion by exotics than established marshes due to the disturbed nature of the site, which is characterized by extensive open ground and low levels of competition (Zelder 1996a; Havens, Berquist, and Priest 2003). There are multiple plant species in southern California that have invaded salt marshes (e.g., ice plant species; Zedler) suggesting that constructed marshes in this area may be vulnerable to establishment by invasives. Without the removal practices, it is likely that invasive plants would cover a much larger area both in the marsh and in the upland habitat at the 5 year-old site. Continued removal of these plants will be necessary to ensure that the slow growing marsh plants are able to fill in the upper zone of the 5 year-old marsh.

The plant community at the 8 year-old marsh was observed to have developed differently than the 5 year-old marsh over time. Plant expansion at the 5 year-old marsh has occurred at a slower rate than the 8 year-old marsh, yet the younger marsh is currently more diverse than the older marsh. As hypothesized, vegetative cover levels at the 8 year-old marsh were not different from the natural marsh in either the mid or low marsh zones. There was no significant increase over the 14 months of this study. There is little area left in the mid marsh zone for further plant expansion. However, there are areas in the low marsh zone where plants can expand. Many of these areas have coarse sediment and it is unknown if the plants will grow in these areas. At the end of the mitigation term in 2002, the vegetative cover in the mid marsh at the 8 year-old site was determined to be 94 ± 6.4% (Beck and Paquette 2003). While vegetative cover found in this study was slightly lower, the decrease was not significant (One-way ANOVA, $p < 0.01$). Plant cover at the 8 year-old site had reached over 50% by the end of the second year (Beck and Paquette 2000) and over 80% by the end of the fourth year (Beck and Paquette 2002). Thus, it appears that vegetative cover in the mid marsh at the 8 year-old site is no longer increasing. The rapid expansion of the vegetation in the mid marsh during the first few years can be attributed to how the marsh was planned. A few plant species that were known to be effective colonizers were used to populate the marsh, resulting in the observed expansion. Unfortunately, planting of the low marsh was not part of the mitigation terms and thus little data were collected on this zone. There were two transects in the low marsh during 2002, one of which had 93% cover and one which had 0.5% cover (Beck and Paquette 2003). It is difficult to determine if the vegetation in the low marsh has increased significantly since 2002 as follow-up data were not collected. However, it does appear that *Spartina foliosa* (the dominant low marsh species) expanded into new areas of the marsh. While there was no increase in vegetative cover over the course of this study, it is likely that there has been plant expansion in the low marsh since 2002. The data for this and the mitigation study were collected using different methods, therefore, differences or lack thereof could be attributed to methods rather than actual biological differences.

Species richness and diversity of the low marsh zone at the 8 year-old marsh were not different from the natural marsh and were higher than those in the 5 year-old marsh. However, the species composition of the 8 year-old marsh was slightly different from the natural marsh. At both sites *Spartina foliosa* was the dominant species. *Salicornia virginica* and *Batis martima* were observed occasionally in the low marsh at the 8 year-old and natural marshes. However, the annual species *Salicornia bigelovi* was the second most abundant species at the natural marsh and was missing from the 8 year-old site. This difference may not be a substantial problem at the 8 year-old site as the average cover of *S. bigelovi* never exceeded 5% at the natural marsh and the average richness and diversity were not different between the 2 sites.

Unlike the low marsh, the mid marsh at the 8 year-old site had significantly lower plant richness and diversity than either the natural marsh or the 5 year-old marsh. While it was expected that the 8 year-old site would have lower diversity than the natural marsh, the lower diversity compared to the 5 year-old site was unexpected. The low diversity and richness of this zone probably directly resulted from the initial planting design for the site as only plants which were expected to expand rapidly were chosen for planting. The plant community at the 8 year-old site is comprised primarily of a mosaic of *Salicornia* *virginica* and *Juamea carnosa* stands with the other species only occurring in a few patches, unlike the natural marsh, which is comprised of many interspersed species. In this study, a single natural marsh with high diversity was examined. Morgan and Short (2002) reported high variability in plant communities among natural marshes and urged caution when choosing reference sites. Other salt marshes in southern California do not always have the high diversity seen at Los Cerritos and can be dominated by only a few species (personal observation). However, these low diversity marshes are often impacted by human development and it is hard to determine if the low diversity has human or natural causes.

The low diversity and richness seen at the 8 year-old marsh could have other implications for this salt marsh community. Keer and Zedler (2002) found that salt marsh assemblages consisting of 5 or more species had more canopy layers than single species communities despite both having 100% cover. Canopy complexity is important for invertebrate habitat as well as for organic matter retention in the marsh (Hooper and Vitousek 1997; Tilman et al 1997). While canopy complexity was not measured in the study, the low diversity at the 8 year-old marsh suggests that canopy complexity may also be low.

No invasive plants were observed in the 8 year-old marsh, which I attribute to the absence of high marsh habitat. Plants that invade southern California salt marshes do so in the upper marsh where they receive no or extremely little inundation by salt water (Zedler 1996a). Thus, I believe that the lack of invasives is a result of site architecture and not biological resilience of the site.

Native plant species not initially planted did not become established in either constructed marsh. The 8 year-old marsh is completely isolated from any other salt marsh habitat (figure 1) and thus, would not be expected to receive propagules from other marshes. The 5 year-old marsh is located relatively close to the natural marsh (figure 1). However, it has been found that there is little exchange of propagules among marshes unless they are located directly adjacent to each other (Huiskes et al. 1995; Lindig-Cisneros and Zedler 2002). Thus, it is unlikely that any propagules would be transported down the Los Cerritos Channel to the 5 year-old site. The findings from this as well as other studies show that constructing a marsh requires careful planning. While the speed at which plants grow and propagate is important and should be given attention, this should not be the only factor considered. Fast growing species such as *Salicornia virginica* do not need extensive introduction to a site (Zedler 1996a), as they will rapidly propagate and, if planted in high densities, will take over a site before other species can become established. Thus, in addition to these few fast growing species, other species should be planted, perhaps in greater numbers, to ensure that the site will not be dominated by a few species.

High levels of vegetative cover at both the 5 year-old and 8 year-old marshes were reached relatively quickly. While plants have filled a constructed marsh in as little as 5 years, this is not common (Levin, Talley and Thayer 1996; Simenstad and Thom 1996; Zedler 2000). Many sites took decades for the plant cover to reach that of natural marshes. In a Virginia restoration site, it took 12 years for the plant community to reach cover levels found in nearby natural marshes (Havens, Varnell, and Watts 2002), while a San Francisco Bay continued to have low plant cover after 16 years (Zedler 1996a).

Similarly, vegetation in a San Diego restoration site had only reached 50% cover after 5 years despite there being a connection with 2 natural marshes (Zedler 1991). All these previous restoration efforts and my observations at Jack Dunster and Golden Shores have shown that vegetative development of a site is highly variable and depends on a variety of factors including hydrology, sediment conditions, and initial planting plans.

Seed Bank Dynamics

Few seeds germinated in cores collected from any of my study sites. Seeds that did germinate represented only a few species. The majority of seedlings developed from the high marsh cores, and many of these seedlings represented invasive species. *Salicornia* sp. were the only common seedlings that represented native salt marsh vegetation. This is consistent with previous findings that salt marsh seed banks are transient, highly variable, and have low diversity (Hopkins and Parker 1984; Hutchings and Russel 1989). It has been found that many species (e.g., grasses) are under-represented in salt marsh seed banks while others (e.g., *Salicornia*) are over-represented (Ungar 1987). Lindig-Cisneros and Zedler (2002) found that *Salicornia* sp. and *Suaeda* sp. were the only salt marsh plants to recruit seedlings in a restored marsh in San Diego. Other studies have found that seed germination does not play a major role in determining salt marsh above-ground vegetation dynamics (Hopkins and Parker; Hartman 1988). While there is extensive open ground for seedling germination in constructed sites, it is unlikely that seed germination will add substantially to the vegetative cover. Most salt marsh plants are rhizomatic perennials that rely on vegetative reproduction rather than sexual reproduction (Huiskes et al. 1995; Lindig-Cisneros and Zedler), suggesting that most of the vegetative expansion in a restored marsh will come from vegetative growth rather than seed germination. However, seed germination may be important for maintaining the diversity of a site. Seeds may provide a way for species to move into areas of the marsh where they were not initially planted. This was observed in the 5 year-old marsh, as *Suaeda* seedlings expanded beyond the original areas in which this species was planted and at the 8 year-old site where *Spartina foliosa* established beyond rhizome reach.

While salt marsh seed banks often have low diversity and density, the numbers of seedlings in this study were far less than found in other studies. The number of seeds that germinate can be in the hundreds, or even thousands in some cases (Baldwin, McKee, and Mendelssohn 1996; Hopkins and Parker 1984; Lindig-Cisneros and Zedler 2002). Hartman (1988), while a studying a New England salt marsh, found seedlings on the order of magnitude seen in this study and hypothesized that it was due to the dominance of perennial species at that marsh. The observation that the plant community at both constructed marshes is dominated entirely by perennials (except for the few *Triglochin concinna* plants at the 5 year-old marsh) could explain why there were so few seedlings at these sites. However, little germination was observed from the cores collected at the natural marsh, which contains multiple annual species, despite being dominated by perennials. The heavy rainfall in the winter of 2004-2005 should have resulted in increased germination in the spring of 2005; however, this was only observed for invasive species.

It is possible that the methods used to examine the seed bank in this study were flawed. It has been well established that environmental conditions such as temperature and salinity affect germination of salt marsh plants (Baldwin, McKee, and Mendelssohn

1996, Kahn and Ungar 1997; Noe and Zedler 2000). Care was given to vary the temperature in which the cores were placed and to provide fresh water in order to maximize the number of species that could germinate. The temperature, light, and watering regimes in this study were similar to others that have examined temperate salt marsh seed banks (Hartman 1988; Hopkins and Parker 1984; Noe and Zedler). Hutchings and Russel (1989) suggested that seeds be separated by hand from the sediment to avoid any bias during incubation. While this technique would have likely affected the results, it does not explain why germination in this study was so much lower than others that have used similar techniques. It is possible that the time of core collection affected germination. Cores were collected in October to try to capture seeds produced over the summer. However, seeds may require time in the sediment before they are able to germinate. Seeds could have germinated in the field prior to the core collection in March. However, few seedlings of non-invasive plants were observed in the field at any point, so this alone could not account for the extremely low numbers of salt marsh plants that germinated.

Based on the results of this study, it appears that seed germination is extremely low in the 2 two constructed salt marshes and is unlikely to have affected the total vegetative cover. It is possible that seed germination has affected plant diversity. However, the seed bank should be re-examined using a variety of methods to determine if the findings of this study truly represent the seed bank dynamics at these sites.

Sediment Characteristics

As anticipated, sediment organic matter at both constructed marshes was lower than the natural marsh, however, it was unexpected that organic matter at the constructed marshes would be lower than the degraded marsh. Organic matter levels in the natural marsh sediments in this study are similar to those found in other West Coast marshes (Langis Zalejko, and Zedler 1991; Simenstad and Thom 1996; Trnka and Zedler 2000; Ward, Callaway, and Zedler 2003). When compared to other constructed marshes of similar age, the 2 constructed marshes fall at the mid-range of sediment organic matter (2-10% AFDW; Langis, Zalejko, and Zedler; Moy and Levin 1991; Simentstad and Thom). At the natural marsh, organic matter in the mid and low marsh was significantly higher in the first 5cm of sediment than in the next 15cm. This pattern was not seen in either of the constructed marshes. Organic matter has been found to accumulate primarily in the upper 10cm of sediment in constructed marshes, with little change over time in the lower sediments (Craft 2000). The low organic content in the 0-5cm depth range suggests that both constructed marshes are still in the early stages of organic matter accumulation. Unfortunately, data on sediment organic matter were not collected at the 8 year-old marsh during the mitigation term so it is unknown if organic matter has increased since construction. The findings of this study are consistent with previous studies, which have found that organic matter is slow to accumulate in constructed marshes (Boyer, Callaway, and Zedler 2000; Craft; Craft et al. 1988; Moy and Levin).

Low organic matter in constructed marshes has negative effects on both the plant and animal communities. Plants tend to grow shorter and less dense in marshes with low organic matter (Havens, Varnell, and Bradshaw1995; Trnka and Zedler 2000). Willis and Mitsch (1995) found that nutrient levels did not affect plant emergence, but did affect biomass after emergence. *Spartina alterniflora* has shown positive responses to increased nutrient conditions by increasing aboveground (leaves and stems) and belowground (roots and rhizomes) biomass (Padgett and Brown 1999; Pennings, Stanton, and Brewer 2002). Thus, constructed marshes may have high percent cover but lower canopy height due to the low organic matter in the sediments. Low nutrient levels may also affect the plants found in a salt marsh by shifting the community to a few species that are able to allocate more growth to roots, thus allowing them to be more tolerant to low nutrient conditions (Barko and Smart 1986; Pennings, Stanton, and Brewer).

In addition to plants, sediments with low organic matter are known to negatively affect the infaunal community (Zedler 1996a). When examining a variety of environmental variables, Talley and Levin (1999) determined that sediment organic content was the variable that explained most of the variability in invertebrate densities. Moy and Levin (1991) found that a constructed marsh in South Carolina with low organic matter sediments was missing deposit-feeding oligochaetes common in a nearby natural marsh and was instead dominated by tube-dwelling, surface-feeding polychaetes. Invertebrate communities in constructed marshes are often dominated by a few species that are well adapted to disturbed conditions (Levin, Talley, and Thayer 1996; Talley and Levin). Thus, while invertebrate communities in constructed marshes may have similar densities as natural marshes, their species composition may differ. When collecting cores for sediment analysis, I observed that the natural marsh contained a variety of invertebrate taxa, including molluscs, polychaetes, and arthropods while the 2 constructed marshes were dominated by surface dwelling isopods with the few infaunal organisms, consisting primarily of polychaetes. Although these differences were not quantified and currently cannot be attributed to sediment conditions, this issue warrants further investigation.

Oftentimes the low organic matter in constructed marshes can be attributed, in part, to sediment that is coarser than natural marshes (Zedler 1996a). Many constructed marshes have coarse sediment as a result of the use of upland or dredged sediment for the creation of the site (Zedler 1996a). Likewise, the upland soil from Riverside County, California used to create the sediment for both constructed marshes in this study (Arkenstall, pers. comm.) caused the soil in both these constructed marshes to be coarser than the natural marsh sediments for all zones. The natural marsh and the 5 year-old marsh contained approximately 10% clay across all marsh zones. However, the 5 year-old marsh had between 40% and 50% sand in the high and mid marsh and over 60% in the low marsh, which was significantly higher than the natural marsh. Thus, the grain size modes were significantly larger in the 5 year-old marsh than the natural marsh. The 8 year-old marsh contained a significantly greater proportion of sand (60-70%) than either the natural marsh or the mid zone of the 5 year-old marsh. Grain size mode at the 8 year-old marsh was extremely large as a result of the high % sand. There was high variability in sediment composition at the 8 year-old site due to sand deposition in some areas of the marsh, which resulted in some areas having over 80% sand and others having less than 40% sand. Sediment grain size was measured at the 8 year-old marsh in the first year after construction. At the time, the sand component of the sediment was 34 ± 14.5% (Paquette 1999). After the first year, sediment data were only collected at one subtidal station in the marsh. In 2002 sediments at this station had 48% sand while in 1999 the same station contained only 15% sand (Beck and Paquette 2003). It is unknown if the sand component has continued to increase since 2002 as data were not collected subtidally in this study. When compared to other constructed marshes, the sediment grain size at the 2 constructed marshes in this study was only slightly higher. Two constructed marshes in San Diego were found to contain 50% sand, on average (Boyer, Callaway, and Zedler 2003) while a North Carolina marsh contained from 25% to 60% sand (Moy and Levin 1991).

In both natural and constructed marshes the top portion of the sediment often contains a greater clay composition due to fine particles settling out of the slow moving water (Boyer, Callaway, and Zedler 2003; Redfield 1972; Zedler 1996a). However, this was not observed in any of the marshes in this study. From the absence of finer sediments in the top portion of the sediments at the constructed marshes, it appears that these constructed marshes are not yet accumulating fine sediments. There has been continual sand deposition in the 8 year-old marsh due to a sand bar located in The Los Angeles River near its entrance. This may be the reason fine sediments do not reach high levels at this site. The 5 year-old site may accumulate finer particles over time. However, this can only be determined with continued monitoring.

Coarse sediments in constructed marshes can have a variety of effects on marsh development. They do not hold water or nutrients as well as fine sediments, which can negatively affect both the plant and invertebrate communities. Barko and Smart (1986) reported that nutrient concentrations were inversely correlated with grain size. Both *Spartina foliosa* and *Spartina alterniflora* have been known to grow taller and at higher density in finer soils with a higher nutrient content (Pennings, Stanton, and Brewer 2002; Trnka and Zedler 2000). In a San Diego marsh, low vegetative height was attributed to coarse sediments that did not retain nutrients (Zedler and Langis 1991). Similarly, a marsh in British Columbia was found to have low vegetative cover as a result of coarse sediments (Zedler 1996a). Coarse sediments also affect invertebrate communities through desiccation at low tide, inadequate nutrients for deposit feeders, and inability to maintain burrows (Zedler).

While there are many possible effects of low organic content and coarse sediment, it is currently unknown which of these are affecting marsh development at the 2 constructed marshes in this study. Organic content was used in this study and others as a proxy for nutrients in the sediment since decomposing organic matter adds nutrients to the sediment. However, it has been found that many salt marshes are nitrogen limited while others switch between nitrogen and phosphorous limitation based on season (Howarth 1988). Thus, it is possible for the sediment to have a large organic component, while simultaneously be limited in an essential nutrient. Sediment and pore water nitrogen and phosphorous should be tested directly at the sites to determine if their concentrations are limiting for the plants. I noticed that the *S. foliosa* at the 8 year-old marsh appeared yellow and stunted in areas where there was extensive sand deposition. This suggests that the plants at this site may not be as healthy as in the natural marsh. Nitrogen concentrations in the plant tissues as well as canopy height should be examined to determine the health of the plants. In addition to the vegetation, I suggest that the invertebrate community should be examined to determine if there are any differences between the constructed sites and the natural site.

Grain size results in this study could have been affected by the analysis method. While roots, rhizomes, and other macro-organic material (e.g., shell fragments) were removed from the sediment prior to analysis, organic matter was not completely digested. This could have altered the grain size estimates at all sites. Any effect would have been greatest at the natural site where organic matter was the highest. However, it is unlikely that this alone could account for the large difference seen between the natural and constructed marshes. Grain size mode was included in the analyses because organic matter likely had little to no affect on grain size mode since pieces of organic matter would likely not constitute the most common size class. The % of fine particles (clay and silt) at the natural marsh was comparable to that found for other natural marshes (Moy and Levin 1991; Simenstad and Thom 1996; Ward, Callaway and Zedler 2003). When broken down into clay and silt fractions, the natural marsh contained approximately 10% and 60%, respectively, in all marsh zones. This is a smaller clay fraction than has been recorded for some other marshes, most of which contained between 20 and 75% clay (Moy and Levin; Trnka and Zedler 2000; Ward, Callaway and Zedler). While this difference could be attributed to the methods used it could also be due to natural marsh variability. The above mentioned studies used sieving and pipette analysis to determine grain size. There have small discrepancies reported when comparing data from the 2 methods and thus care should be given when making comparisons with studies that have used other methods (Hayton et al 2001).

Suggestions For Management

Since construction, both the 5 year-old Jack Dunster marsh and the 8 year-old Golden Shores marsh have made progress towards plant community structure seen at the natural marsh, although both have areas that need improvement or further examination. While the vegetative cover at both sites appears to be at, or progressing towards, natural levels, the species diversity remains low at the 8 year-old marsh. Addition of other plant species could improve diversity at this site. However, *Salicornia virginica* is known to have higher colonization rates than other salt marsh species (Talley and Levin 1999; Zedler 1996a) and would likely impede growth of other introduced plants. Thus, *S. virginica* would likely need to be excluded from portions of the marsh to allow the other species to become established. While this would be time consuming it would likely improve the vegetative community. The vegetation at the 5 year-old marsh appears to be developing properly with high diversity but is missing common annual species. Given the high success of the other species and the fact that this site is still in the process of filling in, these species could likely be added with high success rates. Future restoration projects should initially use a greater variety of species that include both annuals and perennials to ensure that plant diversity will be appropriate as the marsh develops.

Sediment conditions at both constructed sites have not yet developed appropriately. Both sites are lacking in fine grain sediments seen in natural marshes. This could be amended by bringing in fine sediments to the sites. However, at the 8 year-old site where there is continued sand deposition, it is unlikely that the addition of fine sediments would improve the sediment conditions. At some constructed sites where sediment nutrients remained low, nutrient additions to the sediment were performed. These practices have had mixed results. In some cases plant density and height increased, suggesting that nutrient additions may improve the vegetative community (Trnka and Zedler 2000; Zedler and Langis 1991). However, others have found that there was no effect of nutrient addition (Zedler 1996a). In sites with coarse soils, such as the 2 in this study, it is unlikely that nutrients added to the soil would remain in the marsh for long. Instead, they would likely be leached into the waterways. Therefore, nutrient additions may not have any effect on the plant community in the marsh and could instead have a larger impact on the waterways that feed the marshes. It is unknown how the coarse sediments with their low organic content are affecting these marsh communities. As mentioned previously, studies need to be carried out to determine plant health as well as invertebrate community structure. The problems that many created marshes have with sediment development shows that many factors need to be considered when initially constructing a site. If sediment is chosen that is more similar to natural sites, marsh development will likely be more successful.

Site Summaries

Jack Dunster

Vegetation at the 5 year-old marsh appears to be on its way to reaching levels found at the natural site and will likely reach near 100% cover in the next few years. Plant diversity at this site is high, but the marsh is lacking in annuals. This could be easily amended by introducing them to the site from the nearby Los Cerritos Wetlands. Invasive plant cover at the site remains low, primarily due to continued weeding. This practice will need to be continued as the high marsh appears to be filling in at a much slower rate than the mid or low marsh. Without removal of invasives, it is likely that they will occupy the high marsh before the slow growing natives can become established. In addition to removal of unwanted plants, occasional trash removal will probably be necessary. While trash deposition at this site is not as high as the 8 year-old site, large pieces of debris are sometimes brought into the site. Despite the success of the vegetation, the sediment does not appear to be developing as quickly. It is currently much coarser and has a lower organic content than the natural marsh. This invites further investigation to determine what effects this could have on marsh development. Over time this site has the potential to develop into a successful salt marsh and continual monitoring and management should be carried out to ensure that it continues to develop properly.

Golden Shores

The vegetative cover at this site has reached levels found in the natural marsh, but plant diversity remains low. This could be improved by introducing additional species from natural marshes. However, some clearing will likely need to be done to allow the new species to become established. The sediment at this site does not appear to be accumulating fine grain sizes or organic matter and this negatively affects marsh development. Continued sand input from the Los Angeles River will likely impede the increase of both fine particles and organic matter. Studies need to be carried out to determine how the sediment is affecting plants and invertebrates in this marsh. Based on sediment cores taken in this study it appears that the infaunal community is extremely limited. Given the isolation of the Golden Shores marsh, it is unlikely that invertebrates will be able to colonize the site on their own and would likely need to be introduced by hand. Another problem that this site faces is trash deposition. Because it is off the Los Angeles River, large amounts of trash get washed into the site, especially during the rainy season. Without continued trash removal, the vegetation would likely be smothered. In general, this site appears to have developed into a reasonably adequate marsh but improvements should be made to aid further marsh development.

Conclusions

Restoration practices have become commonplace as a way to improve habitat lost or degraded by human practices and are, in fact, required by governmental regulations. However, it is unlikely that we will ever be able to recreate the natural habitat that has been lost. Constructed marshes are often small and isolated in addition to containing different hydrological, sediment, and nutrient conditions from natural marshes, which in turn results in different vegetative and faunal communities in constructed marshes. Thus, these constructed marshes are unlikely to function as natural habitat once did. The above mentioned conditions could be enhanced by improved planning prior to construction. The use of upland soils in these marshes results in sediment conditions that are often very different from natural marshes, which in turn affects all other aspects of the marsh. More attention should be given to the sediment in early stages of planning to ensure that the most appropriate sediment is used during construction. In addition, the vegetative planting plans should be designed to mimic nearby natural marshes as closely as possible as these plans will determine how the plant community develops in the future.

Despite being different from nearby natural sites, restored and created marshes do provide some natural habitat in areas that are often severely deprived of such habitat. The plant communities at the 2 created salt marshes in this study appear to be relatively successful; however, the sediment conditions remain extremely different from a nearby natural marsh. Continued monitoring of the plant community and sediment conditions is necessary to ensure that both continue to develop properly. In addition, the faunal community should be examined to better understand how the marshes are developing. While this study provided baseline data on the vegetative community and sediment conditions at Jack Dunster and continued the monitoring at Golden Shores, both sites will need continued attention to ensure that they sites remain successful.

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