# Final Report

# Science Based Monitoring of Created Wetlands and Restored Habitat within the Galveston Bay System

**Prepared for the Coastal Management Program of the Texas General Land Office and the National Oceanic and Atmospheric Administration**

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## Introduction

Coastal marsh ecosystems in Galveston Bay and along the upper Texas Gulf coast are critical to the ecologic function of many species among many trophic positions. These marshes are typically anchored by smooth cordgrass (*Spartina alterniflora*). *Spartina* marshes are some of the most highly productive communities in the world; they export nutrients into the estuary, function as wave buffers in times of tropical storm activity, provide shelter and nourishment for the juvenile stages of many marine invertebrates and fish, and serve as habitat for resident and migratory waterfowl. For example, shrimp and blue crab production has been correlated with the availability of wetland habitat in estuaries, and habitat use modeling suggests that tidal fringe and submerged aquatic vegetation is more valuable than non-vegetated shallow bottom when examining habitat use by brown shrimp (Minello, 2004 and references therein). Additionally, benthic infauna that are nutritionally important for penaeid shrimp have been found to be most abundant in vegetated habitats within lower Galveston Bay and shrimp growth has been shown to be positively correlated with the abundance of marsh epiphytes and phytoplankton (Minello, 2004 and references therein).

*S. alterniflora* will grow naturally wherever the sediment type and salinity regime are conducive. However, estimates indicate that wetland loss in the Galveston Bay System has exceeded 45,000 acres since the 1950’s (White, et al., 1993). Much of the loss has been attributed to subsidence, conversion to upland uses, isolation of wetlands, and dredge and fill activities (White et al., 1993; Ward, 1993). The Galveston Bay Plan (Galveston Bay National Estuary Program, 1995) identifies lost or degraded habitat as a top problem in the bay system; the plan’s first priority is to protect and restore coastal wetland habitats. In support of this mission, several million dollars have been spent creating and/or restoring numerous estuarine marshes in the Galveston Bay system over the past 20 years. As these projects have been implemented, the methodology has evolved concurrently based on “lessons learned” during the construction and implementation. Projects have evolved from simply planting along a shoreline that appears suitable, to construction of terraces, mounds, and islands of various sizes and shapes to create variations in elevation and marsh edge, which is an important characteristic of marshes and provides habitat for a number of different species. Dredge material is commonly used for marsh restoration activities, and can involve the use of wave breaks and containment levees.

In general, the success of individual projects has been measured by either the vegetated area created (acre/acre) or by the amount of fringe (low) marsh created (linear foot/ acre). Although some of these created/restored marshes have been monitored for plant density (primarily *S. alterniflora*), marsh expansion, and use by nekton, there remains limited information regarding functional success achieved by created marshes, or comparing different restoration methodologies. Some studies indicate that there may be a need to evaluate created and restored marshes to determine success at the functional level and tailor restoration strategies accordingly. Minello and Webb (1997) found that some created marshes in their study had significantly lower densities of decapod crustaceans than natural marshes as long as fifteen years after construction. This suggests that the productivity of a created marsh may not be a simple matter of planting the appropriate vegetation, but may be related to other factors demonstrated to be important in natural marshes, such as sediment composition, infauna, and total low marsh edge (Minello, 2004; Rozas and Minello, 2001; Whaley and Minello, 2002).

Our first Coastal Management Program project in 2007-2008 (referred to from this point as the 2008 study) examined whether functional differences are achieved through different marsh restoration techniques. Our present study evaluates the same parameters five years (and a major hurricane) later. The study area, Pierce Marsh, is comprised of 2,346 acres of mixed high, mid, and low marsh surrounding an open water embayment. Nestled between Highland Bayou to the north and Basford Bayou to the south, and located along the Central Migratory Flyway, Pierce Marsh supports wintering ducks as well as a variety of shore and wading birds, and supports invertebrate and vertebrate fishery species, which rely on the protected waters of the marsh for breeding and foraging (GBF, 2003 and

2008). Fresh water into the marsh is primarily a result of inflows out of Highland Bayou and limited sheet flow from adjoining uplands. Fresh water inflows are balanced against tidal inputs of brackish and saline water from west Galveston Bay to the south. Hydrologic changes to the site were caused by a combination of ground subsidence and development diverting overland sheet flow and reducing the supply of nutrients and sediment to the marsh. Large areas of emergent marsh within the Pierce Marsh complex became open water as a result of land surface subsidence. Subsidence rates have been reported to have declined from their maximums (Harris-Galveston Coastal Subsidence District 1998), making restoration of wetlands that have become shallow open-water possible.

Wetland restoration in Pierce Marsh began in 1999 and has proceeded as funds have been available through 2011. A primary reason for choosing Pierce Marsh as the study location for this research was that several different restoration projects have been conducted within this single marsh complex, allowing for a more direct comparison among different techniques than would examining restoration projects located more distally and subject to different environmental factors (i.e., salinity regimes, sediment regimes, etc.). Restoration techniques within Pierce Marsh include an assortment of methods, primarily centered on variations of terracing techniques where shape and relative position of the terraces differ. Terracing involves “borrowing” sediments from the bottom and stacking them to form linear berms which are then planted with *S. alterniflora* at an elevation generally between the low and high tide lines (Fig. 1). An alternate method also represented in Pierce includes a beneficial uses marsh composed of a leveed area (the levees themselves are similar in appearance and structure to the terraces) arranged to trap fluid sediments pumped in using a hydraulic dredge until elevations of the ultimately consolidated material within the levees are sufficient to support *S. alterniflora*. The fill within the levees often takes on an irregular elevation across the cell, resulting in a mosaic of elevations and flooding characteristics throughout each cell.

Five areas of the marsh have been the focus of low marsh restoration efforts since 1999 (Fig. 2 and Fig. 3):

1. Grid terraces (PRC3 or GRD): constructed in 1999; 153 terraces in a 63-acre area
2. Sinusoidal terraces (PRC4 or SIN): constructed in 2001; 41 terraces within a 49-acre area, and including oyster shell on the crown of each terrace for colonial bird nesting use
3. Zigzag terraces:
    a. PRC2 or ZIG2: constructed in 2004; 49 terraces within a 25-acre area
    b. PRC6 or ZIG6: constructed in 2011; 48 terraces within a 25-acre area [new to the present study, in the 2008 project, open-water bay bottom samples were collected in this location]
4. Beneficial uses marsh (PRC5 or BUM): constructed in 2005; approximately 200 acres total within the levees

Design of each restoration site was conducted by a professional engineering company, and executed in the field by professional contractors. Planting at each site was conducted by volunteers, often over the course of several weeks of months, depending on the availability of plants, transportation, and volunteers (GBF, 2003 and 2008).

The choice of the different designs among the original four sites was related to needs-based criteria, such as the need to maximize low marsh edge and minimize erosive wave fetch, incorporate specific habitat types (i.e., nesting habitat for colonial waterbirds), the area (acreage) and bathymetry in which the restoration is to occur, the texture and consistency of the sediments in the restoration area (important when considering the settlement rates of the terraces), and the availability of sediment (i.e., beneficial use of off-site dredge material or use of on-site borrow material). Design changes from one restoration project to the next are often selected to address perceived problems in previous restoration efforts based on observation after the restoration sites are completed (i.e., to increase water flow through terraces or reduce wave fetch from boat traffic). Reports post-construction often indicate success, based on anecdotal observation with little “hard” data beyond simple plant coverage.

Previous research in Galveston Bay and other locations has indicated that there are nearly always significant functional differences between created/restored marsh and a natural reference marsh, particularly in infaunal and nekton densities (Rozas et al., 2005; Rozas and Minello, 2001; Minello and Webb, 1997). Studies have also indicated the importance of increased marsh edge when examining natural reference marsh production relative to created marsh production (Rozas and Minello, 2001; Whaley and Minello, 2002). The organic content of reference marshes relative to created marshes has also been noted as significant, as has the "mosaic" or patchy nature of the marsh edge and vegetation in natural reference marshes relative to terraced marshes (Edwards and Proffitt, 2003; Feagin and Wu, 2006; Minello and Webb, 1997).

The 2008 study assessed the function of four restored sites within the Pierce Marsh complex on West Galveston Bay, relative to a natural, unrestored control site in the same complex. Pierce Marsh offers a unique opportunity to study several different marsh community parameters within several restoration sites that have utilized different restoration techniques all within one general area or complex, which aids in comparison between the sites as they would ostensibly be subject to the same general range of water quality and other environmental conditions that might otherwise alter biologic communities at the sites. Function of each study site was assessed by examining the sediments (component analysis), macrobenthic community composition, and plant density and biomass.

The present study revisited and expanded upon the same parameters and sites sampled in the 2008 project, in order to evaluate the effects of five years' time and the occurrence of a major hurricane (Ike, September 14, 2008). In addition, an open water area sampled in 2008 was the site of a new zigzag terrace marsh restoration effort in 2011, adding a fifth research area to the study, providing us the opportunity to monitor ecologic functional development from the preconstruction phase.

The specific objectives of this study were to

1. Compare five restoration sites within Pierce Marsh to a natural, unrestored reference site within the Pierce Marsh complex and to each other by measuring the function of the biotic community of each via
    a. Plant species richness and coverage
    b. Dominant plant (*Spartina alterniflora*) productivity (biomass and shoot height)
    c. Benthic macroinvertebrate community composition
    d. Benthic microbial community composition
2. Compare 2013 results to data collected from the same sites and stations in 2008 to evaluate
    a. Physical and biological changes in each restoration design over the five year interval
    b. Physical and biological baseline data for a newly constructed terrace marsh construction on a previously open water site
    c. Possible influence of Hurricane Ike on erosion and subsequent sediment deposition at the restoration sites.

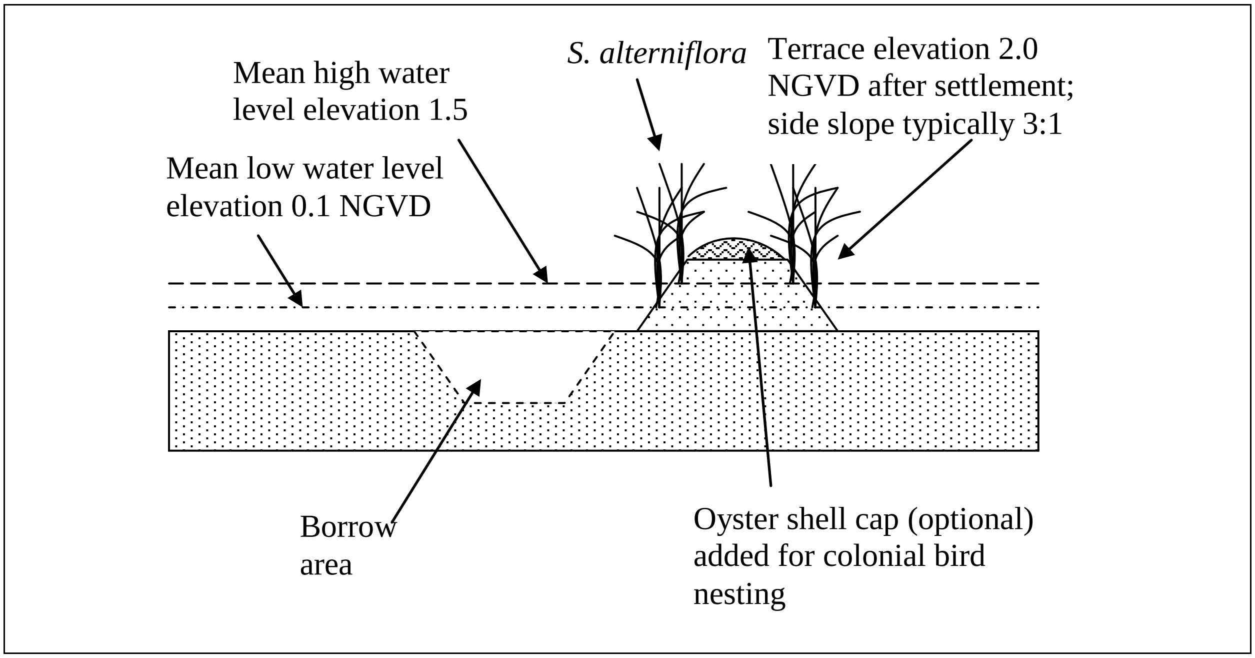

Figure 1. Cross sectional view of typical terraces constructed at Pierce Marsh. Water level elevations are determined from via bathymetric survey. Typical terrace elevations and water levels are given in National Geodetic Vertical Datum (NGVD). Terraces were constructed with a 3:1 side slope using material taken from the adjacent borrow area.

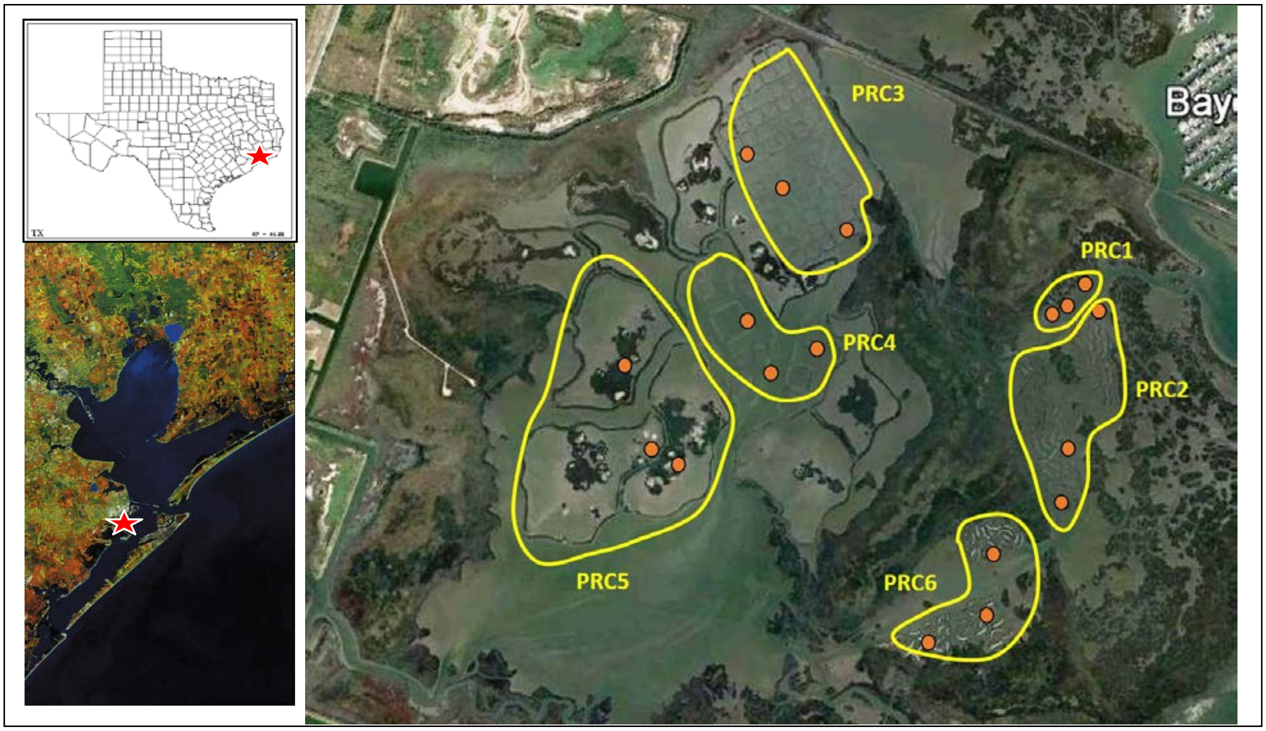

Figure 2. Aerial view of Pierce Marsh complex showing the locations of the reference site (PRC1), four original restoration sites (PRC2-5), and the newest restoration site at a formerly open water site (PRC6).

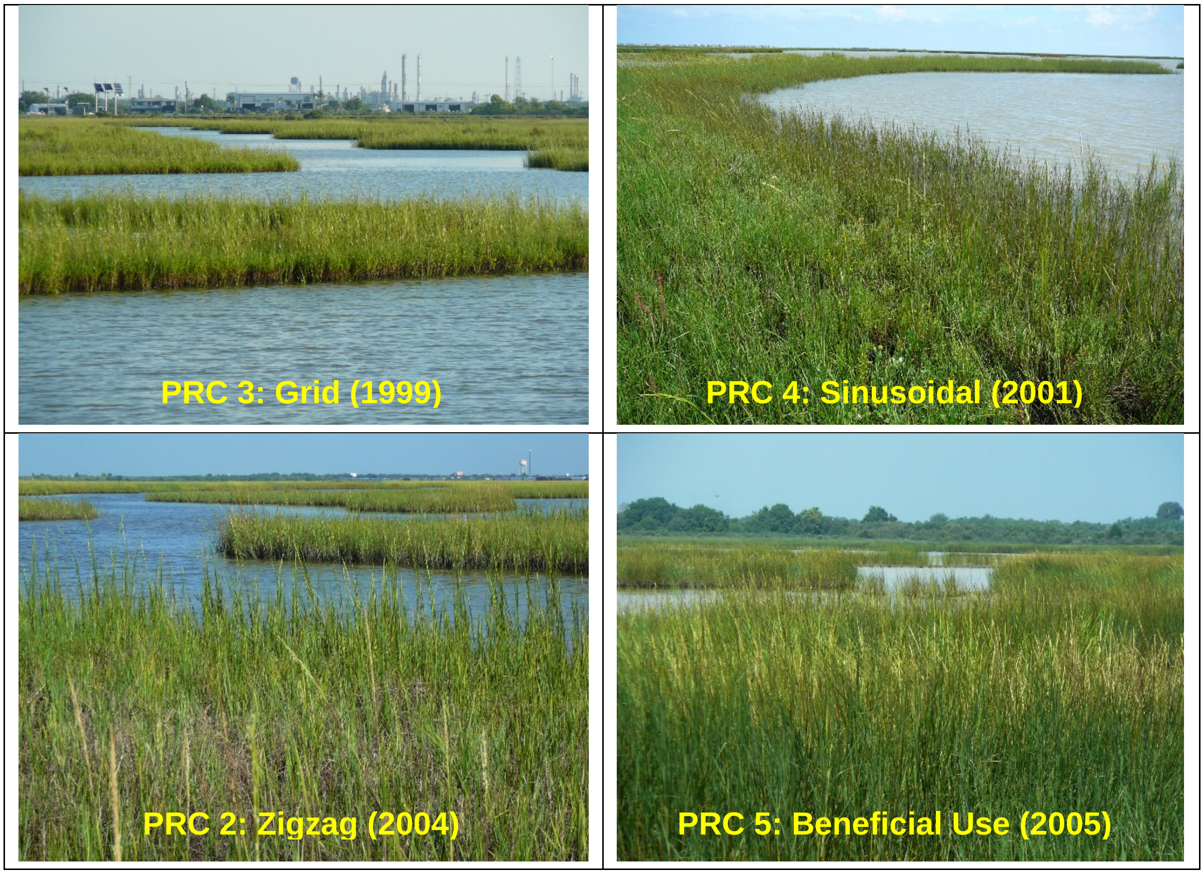

Figure 3. Photographs of the four designs used to restore marsh habitat in the Pierce Marsh complex, with dates the sites were constructed and planted with *S. alterniflora.*

## Methods and Materials

### Site selection

Sites were selected for the 2008 study using an aerial map of the Pierce Marsh complex overlain with a numbered grid pattern. The locations of three transects (A, B and C) for each restoration type were selected using a random number generator (Fig. 2). The same sites and transects were resampled during the present study. As the open water site (PRC6) had been converted to a zigzag terrace marsh in 2011, transects for this site were selected as close as possible to the areas sampled in 2008.

### Field sampling

The Pierce Marsh reference and restoration sites were sampled in June 2013. Access to the sampling areas was provided by airboat. GPS coordinates recorded during the 2008 study were used to locate PVC stake markers that were left in 2008. Plant and sediment samples were collected from the same sites, transects and stations established in 2008.

Transects at the reference (REF) site started at the marsh edge and extended 20 meters into the marsh, perpendicular to the edge. Three stations were sampled along each transect: one at the origin (Station 1), one at the 10-m mark (Station 2) and one at the 20-m mark (Station 3).

Transects at the restored sites (GRD, SIN, ZIG2, ZIG6 and BUM) were established by setting the origin at the stake on the edge of one side of the berm and extending the line 20 meters across the berm to the marker at the edge on the other side. Three stations were sampled along each transect: one at the origin (Station 1), one at the 10-m mark in the center of the berm (Station 2) and one at the 20-m mark on the opposite side (Station 3).

Sediment core samples were collected for heavy metal, benthic macroinvertebrate and benthic microbial community analyses. Samples were collected using a Lexan plastic 2-inch diameter core tube inserted directly into the sediment to a depth of 4 inches (benthic community) or 2 inches (sediment chemistry). Samples were placed into 1-qt ZipLoc freezer bags, 10% buffered formalin was added to the benthic macroinvertebrate samples, and all samples were transported to the UHCL laboratory.

At each station, a 1/16m$^2$ plot was set to the right of the transect and a 1/4m$^2$ plot was set to the left. All shoots of *Spartina alterniflora* in the 1/16m$^2$ plot were counted and recorded (shoot density), then all *S. alterniflora shoots* and roots were dug out of the plot and placed in large plastic trash bags for transport back to the laboratory. All plants in the 1/4m$^2$ plot were identified and their relative coverages within the plot were recorded, as well as the percentage of the plot that was unvegetated. Three additional shoots of *S. alterniflora* were collected randomly from within three meters of the station and shoot length and chlorophyll comparison index (Minolta SPAD 1500) were recorded for each plant. All leaves were then removed from the shoot, placed in 1-qt ZipLoc plastic bags and placed on ice for transport to the laboratory. Once at the lab, all leaf samples were stored at -70°C until analyzed for stress biomarkers as part of a parallel project.

### Laboratory analyses

The 1/16m$^2$ plot samples were washed to remove sediment and all of the shoots were carefully separated from the roots. Shoot and root material from each station was weighed (wet weight), then dried separately at 105°C for 24 hours and reweighed (dry weight). Biomass was recorded in grams dry weight.

The benthic macroinvertebrate samples were processed as follows. Upon return to the laboratory at UHCL, samples were logged into the sample receiving log book. Each benthic core sample was washed through a #35 (0.5 mm) mesh sieve, using a gentle stream of tap water. All material remaining on the sieve was transferred to an 8-ounce plastic jar and was represerved in 10% buffered formalin and stained with 50% Eosin B and 50% Sudan IV to facilitate sorting the organisms. Prior to sorting, the samples were rewashed over a #200 mesh sieve and represerved in ethanol. All benthic samples were sorted under low power on a stereo dissecting scope; organisms were identified to the lowest possible taxon, enumerated, recorded and stored in 1-dr vials.

The benthic microbial samples were processed as follows. Sediment dilutions were made by mixing 1g of wet sediment sample from the top 2cm of the sediment sample with 99mL of autoclaved deionized water in a 250mL Erlenmeyer flask to make a 1:10 (wt/vol) dilution. The flask was hand shaken for 5 minutes to promote adequate mixing. A second dilution was made by transferring 25mL of the sediment suspension to 75mL autoclaved deionized water (75% dilution). Using a sterile pipette, 0.2mL was transferred from the Erlenmeyer flasks to the standard plate count agar plates using standard plating techniques, and each sample was replicated three times in order to obtain a viable amount of the colony forming units (CFU) for the culturable aerobic microbes in the sediment. The agar plates were grown for 48 hours under normal growth conditions for environmental microbes at 28$^{o}$C with 40-W fluorescent bulbs. After 48 hours a count of the different colonies was conducted and each of the different colonies were isolated using standard isolation of pure culture techniques. The isolated culture plates were then grown again for 48 hours under normal growth conditions for environmental microbes at 28$^{o}$C with 40-W fluorescent bulbs.

After 48hrs, the isolated pure cultures were transferred to carbohydrate and nitrate substrates. The four carbohydrate substrates used in this experiment were xylose, arabinose, galactose and glucose. The four carbohydrate substrate mixtures were made adding 10g of each carbohydrate to an individual liter of phenol red (a pH indicator) and autoclaved for 10 minutes at 118$^{o}$C. Then 12mL of each carbohydrate phenol red mixture was added to individual test tubes with Durham tubes along with an individual microbe colony for each array of the four carbohydrates. The phenol red pH indicator made it possible to determine which carbohydrate substrates were being utilized by the microbes by changing color from red to orange or yellow. To determine if nitrogen-reducing aerobic microbes were present, a nitrate disc and an individual microbe colony were added to a test tube with a Durham tube along with 10mL of nitrate broth. Then all of the carbohydrate phenol red test tubes and the nitrate test tubes were grown at 28$^{o}$C for 72 hours. Color change and gas production results for the carbohydrate phenol red test tubes were recorded every 24 hours. After 72 hours, gas production was recorded in the nitrate tubes and nitrate reagents A, B and C were added to the tubes to determine if the microbe utilizes nitrate. After adding nitrate reagent A and B, if a color change from clear to pink or red occurred, then the microbe was positive for nitrate reducing. If no color change occurred, then nitrate reagent C was added and if a color change occurred at this step, the microbe did not reduce nitrate. The ability of each microbe culture to reduce nitrate to nitrite was determined using standard BD Diagnostic systems procedure. The results for each of the nitrate test tubes was recorded.

### Analysis of data

Data from all field and laboratory analyses were entered into Excel spreadsheets. Analysis of variance was used to determine significant differences ($p \leq 0.05$) between the reference and restored sites (independent variable) and plant metrics, productivity, sediment chemistry, benthic macroinvertebrate community and microbial community data (dependent variables). All statistical analyses were conducted using Minitab v.16 software.

## Results and Discussion

Within the Pierce Marsh complex, an undisturbed reference site (REF) and five restoration sites (GRD, SIN, ZIG2, ZIG6 and BUM) were studied in this project. At each site, sediment and plant material from three stations along each of three transects were collected in June 2013 (a total of nine stations per site). This study was designed to compare the ecologic function of the different restoration designs in Pierce Marsh between five years of natural influences.

The sediment used to create the grid terraces (GRD / PRC3), the sinusoidal terraces (SIN / PRC4) and the zigzag terraces (ZIG / PRC2) came from adjacent bay bottom. The sediment in the beneficial use material (BUM / PRC5) leveed site was donated from within the canal system of a nearby development that was started, but not finished in the 1970's; this material was collected in the previously dredged canals until a new developer purchased the site and elected to renovate the previously existing canals. Variables important to consider in analyzing which, if any, of the designs is the most ecologically successful include the age of the restoration site at the time of this study (which ranged from two to fifteen years) and the actual design strategy.

As in 2008, sediment samples from each station were acid digested and heavy metals were determined by ICP (inductively coupled spectrophotometry). Comparing 2008 to 2013 raises a number of questions that require further inquiry (Fig. 4). A possible explanation could relate to sediment deposition in the months following Hurricane Ike. Factors related to the ICP analysis could also have contributed to the observed differences.

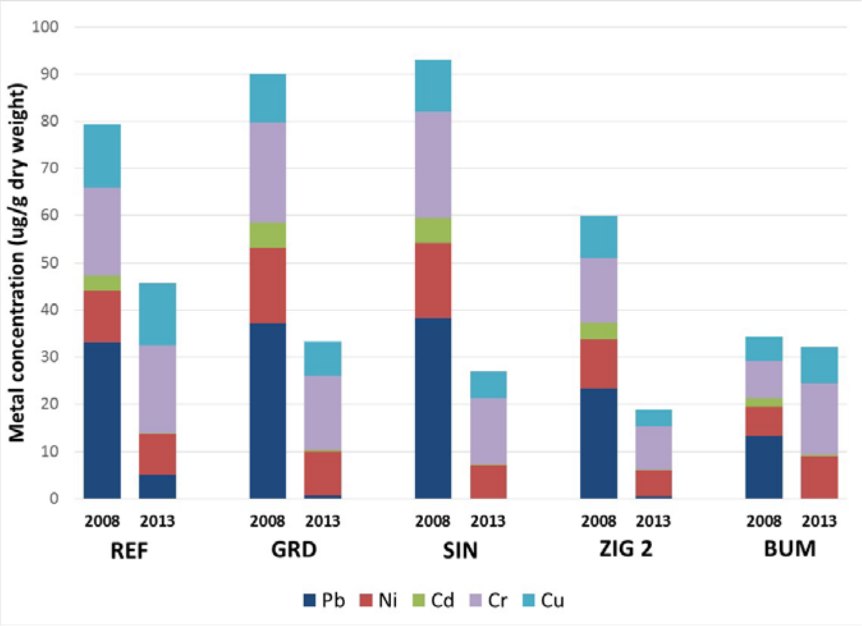

Figure 4. Comparison of selected sediment heavy metals among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

## Changes in site morphology between 2008 and 2013

Marked erosion was evident at three of the four previously sampled sites, particularly GRD and SIN (Fig. 5). GRD and SIN terrace berms that were solid and

2-3 m wide in 2008 had been reduced to unstable, undercut sediment <0.5 m wide in some cases. Category 2 hurricane Ike swept through the area one month after the 2008 sampling event and may have started this erosional process. However, during the same time interval, the BUM site accreted sediment and greatly expanded in size (Fig. 6).

Figure 5. Visual negative changes in morphology in GRD terraces from 2007/2008 (top left) to 2013 (top right) and in SIN terraces from 2007/2008 (bottom left) to 2013 (bottom right).

Galveston Bay Foundation
Aerial support provided by LightHawk

Fig. 6. Visual positive changes in morphology at the BUM site transects from 2008 (photos on left side) to 2013 (photos on right side).

## Changes in the Pierce Marsh plant community between 2008 and 2013

As in 2008, the total plant coverage was significantly higher ($p \leq 0.05$) in the REF marsh (90%) than in the restored sites (35-65%), with coverage in the two ZIG sites less than half of that found in the REF site (Fig. 7). Total coverage at both ZIG sites was negatively affected by the absence of *S. alterniflora* at the berm midpoints (Station 2). Coverage by *S. alterniflora* increased from 40% (2008) to 50% (2013) at the REF site, but decreased significantly at all of the restoration sites over the same time period. The decrease in *S. alterniflora* percent cover at the BUM site was balanced by the successional increase in species richness, as *S. alterniflora* had been the only species present in 2008. Similarly at ZIG2, S. alterniflora cover decreased as cover by other species (in particular, *Batis maritima*) increased.

Of greatest concern is the nearly complete loss of *S. alterniflora* cover at GRD and SIN (<2% at each site). The decrease in terrace berm integrity at both sites has resulted in a loss of suitable substrate and tidal regime for *S. alterniflora*; these sites were instead dominated by *B. maritima* and *Borrichia frutescens* in 2013.

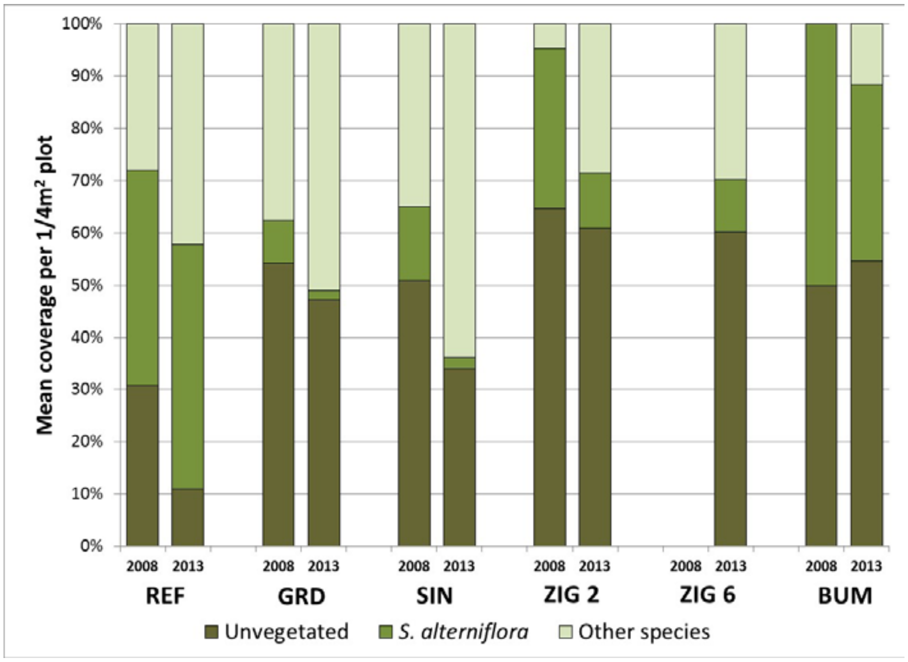

Figure 7. Comparison of total plant cover and *S. alterniflora* cover among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

As in 2008, the biomass of *S. alterniflora* shoots was significantly higher ($p \leq 0.05$) in the REF and BUM marshes than in the other restored sites, with lowest shoot biomass occurring in ZIG (Fig. 8). In addition, the mean shoot length of *S.*

*alterniflora* at REF was significantly higher than at any of the restored sites (Fig. 9); however, comparisons between 2008 and 2013 cannot fairly be made since the samplings took place at different points in the growing season (late summer 2008 versus early summer 2013). As chlorophyll *a* values, as determined by the chlorophyll comparison index (Biber, 2007), followed a similar pattern, the data are not shown.

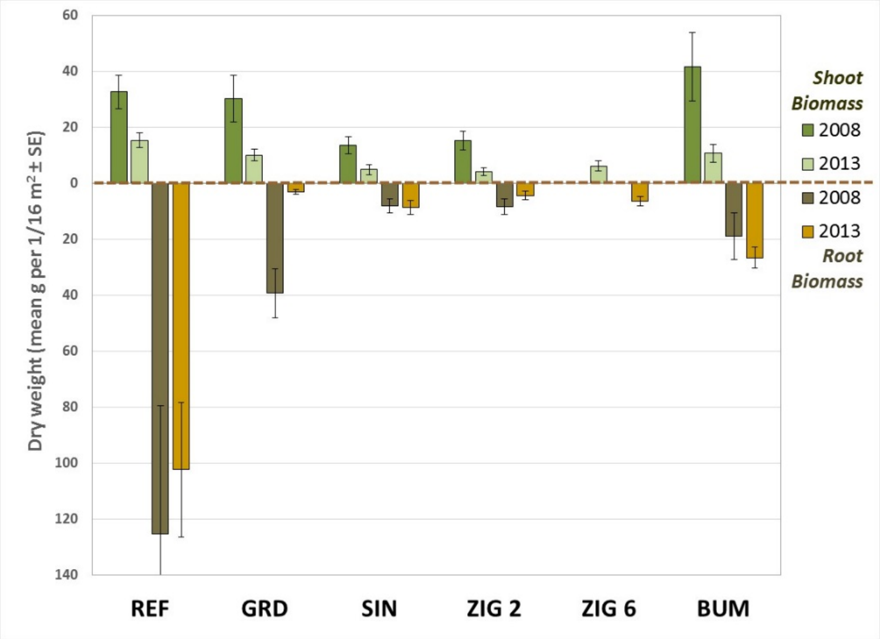

Figure 8. Comparison of shoot and root biomass of *S. alterniflora* among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

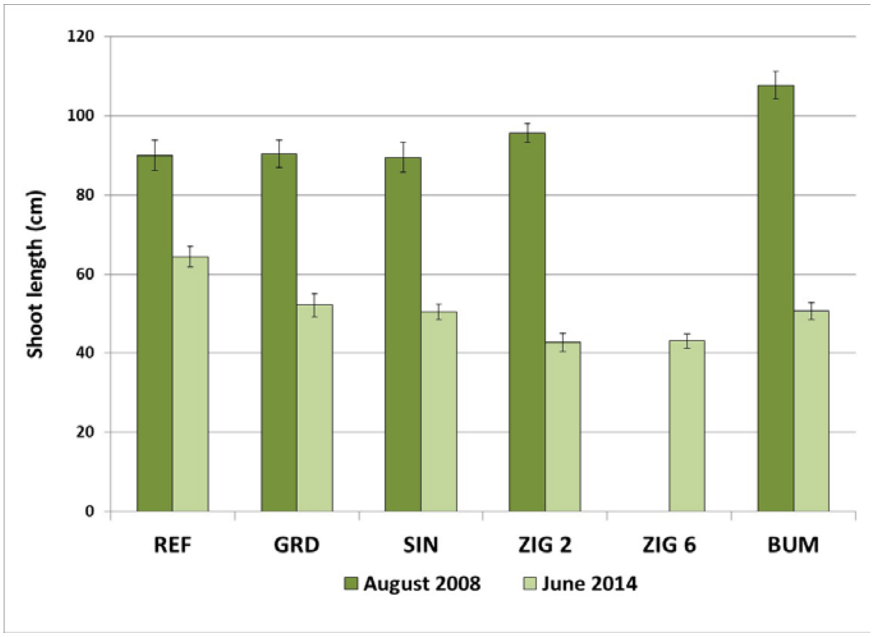

Figure 9. Comparison of individual *S. alterniflora* shoot length among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

One of the most striking results of the 2008 study, continuing in 2013, was the difference in *S. alterniflora* root biomass among the sites. Root biomass in *Spartina* from the REF marsh was many times higher than that from the restored sites (Fig. 8). The age and undisturbed nature of the REF marsh surely factored into the tremendous root biomass; however, there was no relationship between site age and root biomass at the restored sites. High root biomass is essential to the overall productivity and ecological services provided by salt marshes, e.g., stabilizing sediments and exporting nutrients.

Mean species richness at REF, GRD and SIN did not change significantly from 2008 to 2013, although the total richness at each of these sites declined (Figs. 10 and 11). Total and mean species richness both increased significantly at the BUM restoration site, indicating the occurrence of some successional maturation.

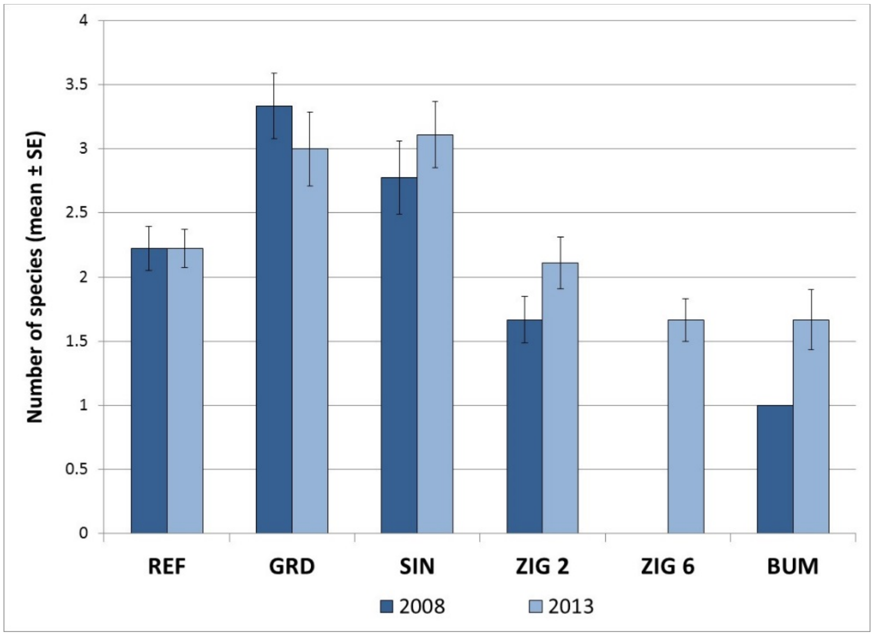

Figure 10. Comparison of average plant species richness among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

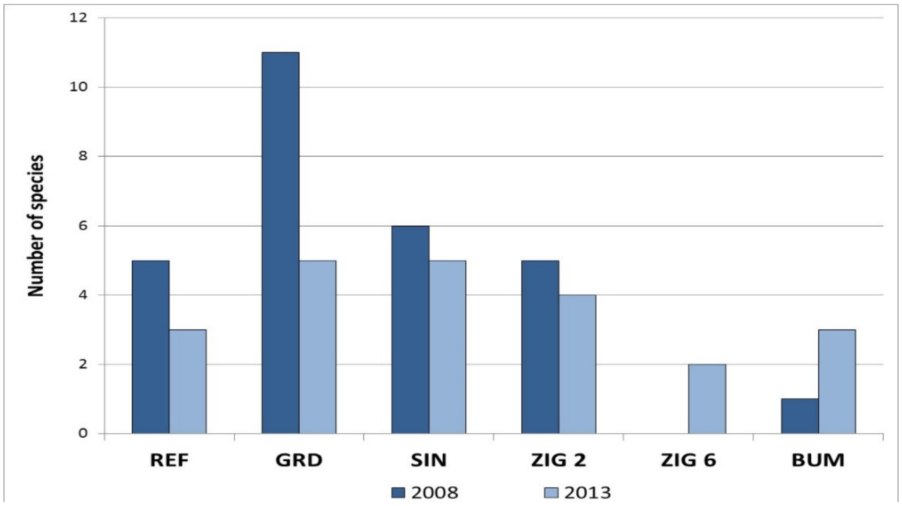

Figure 11. Comparison of total plant species richness among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

A comparison of the 2008 and 2013 Importance Values calculated for the plant species is shown in Figure 12. It can be seen that the sites experiencing the most severe erosion (GRD and SIN) also exhibited decreased *S. alterniflora* cover and total species richness. In addition, the percent cover by *B. maritima* increased significantly at the eroded sites between 2008 and 2013, as well as at the older ZIG site and REF.

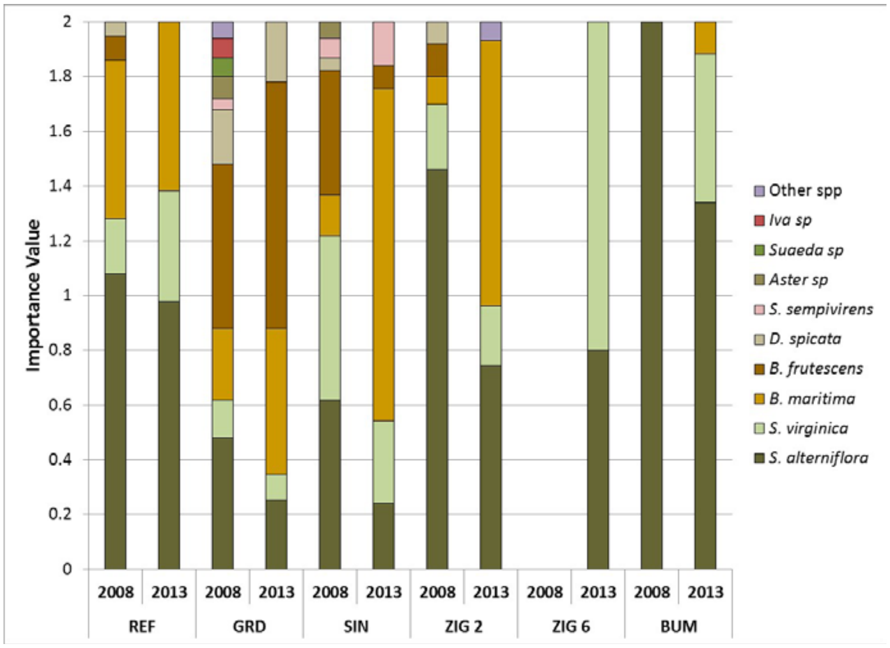

Figure 12. Comparison of plant species distributions and Importance Values (relative frequency + relative coverage of each species) among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

Pierce Marsh benthic macroinvertebrate and microbial communities in 2013

There were significant differences among the Pierce Marsh sites in the number of benthic macroinvertebrate species and in the species composition of each community (Fig. 13). Benthic macroinvertebrate richness and total abundance at the REF, SIN and BUM were at least double the values found at GRD or the two ZIG sites, due to high numbers of nematodes and polychaetes at these sites. BUM also hosted high numbers of Diptera (predominantly Chironomidae larvae). It is interesting to note that even though highly degraded, there was a significant number and diversity of benthic macroinvertebrates present.

Maximum benthic microbial species richness and number of colony forming units occurred at the REF site (Fig. 14). Both indicators were significantly higher at REF than richness and abundance at all of the restored sites; the restored sites did not vary significantly among each other. This is more evidence that the restored sites, due to age and/or design, are not functioning at the level of the REF site.

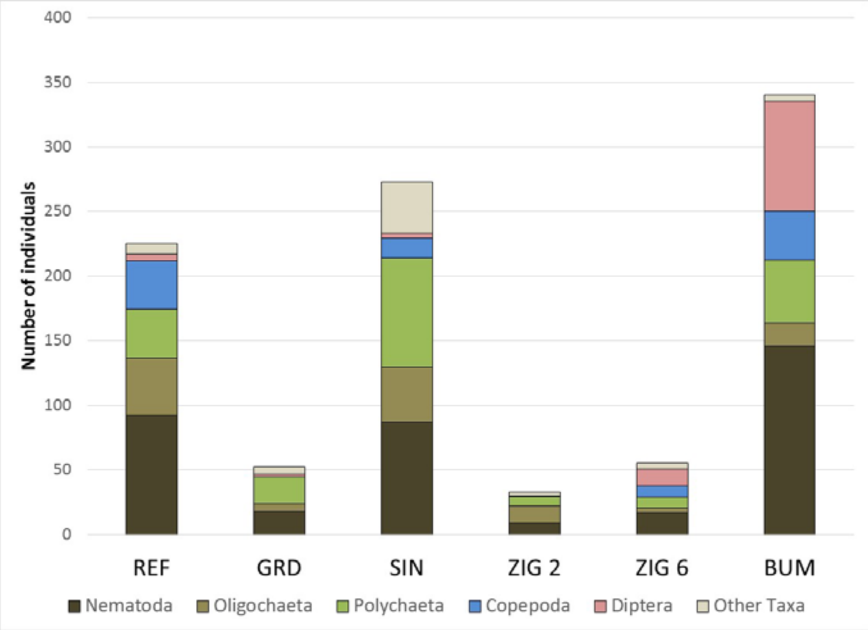

Figure 13. Comparison of benthic macroinvertebrate community taxa and abundance among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

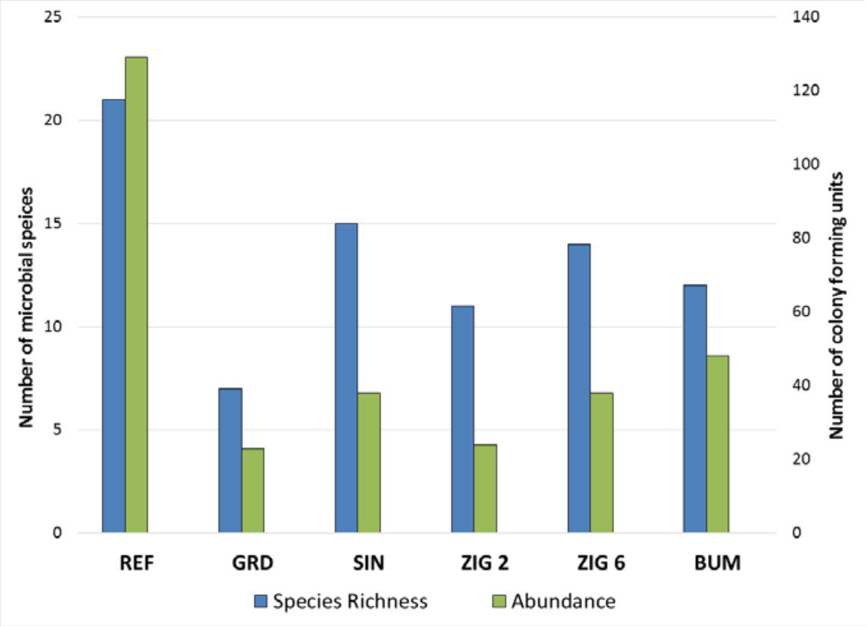

Figure 14. Comparison of benthic macroinvertebrate community taxa and abundance among reference and restoration designs in the Pierce Marsh complex, 2008 and 2013 (REF =

reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

## Conclusions

Recent studies examining restored estuarine marshes indicate that significant differences are typically found between the restored sites and comparable reference sites (Delaney, et al., 2000; Edwards and Proffitt, 2003; Feagin and Wu, 2006; Minello and Webb, 1997; Rozas et al., 2005; Rozas and Minello, 2001; Whaley and Minello, 2002). Possible reasons for these differences have been attributed to an outright lack of low marsh edge and/or erosion at the marsh edge of terraces (Delaney, et al., 2000; Rozas and Minello, 2001), to differences in sediment content (Edwards and Proffitt, 2003), to irregular patterns of plant growth, and the corresponding low marsh edges and subsequent flooding characteristics found in natural marsh v. terraced marshes (Feagin and Wu, 2006; Minello and Webb, 1997).

Pierce Marsh offers a unique opportunity to examine these restored marshes at a functional level over a number of years as they transition from newly created marsh systems to a state of peak function and services. Here, different restoration methods can be directly compared, as these systems are subject to very similar environmental factors (i.e., sediment regimes, salinity regimes, etc.). This study examined whether functional differences are achieved through different marsh restoration techniques. While this is made somewhat difficult due to the relative age of each restored site, real differences were noted among the restored sites, and between the restored sites and the reference site, particularly when examining macronutrient values in the sediments and corresponding shoot densities, and when examining plant productivity among the sites.

This study should be viewed as a midpoint study for ongoing data accumulation for these factors over a several year period. Based on this study (2013) and the previous one (2008), none of the four restoration designs is functioning at the same level as the reference site, although the BUM design looks most promising. This would agree with other research conducted in Pierce (Feagin and Wu, 2006;

Rozas et al., 2005). These studies also recommend that restoration projects should maximize the area of marsh vegetation and create a high degree of water to marsh interspersion in order to function at a level most representative of low marsh reference systems (Feagin and Wu, 2006; Rozas et al., 2005).

The BUM design is substantially different in restoration methodology than the other three. This site appears to include, by virtue of the irregular pattern of elevation created by the fill in the levees, an interspersed edge similar in outright appearance to the reference marsh. As this site was restored less than 10 years ago (2005), it is obviously still in transition, but most closely resembles the reference marsh in overall function. It will be interesting to continue to track the development of the plant and infaunal communities, as well as changes to the sediments that may occur as these communities mature, to see which, if any, of these sites achieve a functional equivalence to the reference site and how long that may take among these sites.

The study team is pleased to be able to present these results, and wishes to express our appreciation for the state's support for this research. The results of this study help address knowledge gaps that are important to imporving our understanding of these complex systems. This is important when considering the ongoing stresses coastal and estuarine marshes are likely to face over the next century, and need increasing need to restore these important systems in order to maintain their ecologic, economic, and societally important functions and services. In an effort to share this data, the study results have been presented in part at the 2013 Texas Association of Environmental Professionals Conference (Houston, TX), and have been accepted for presentation at the 2014 Restore America's Estuaries Conference in Washington, DC. Finally, since the beginning of this project, we have been working with the Houston Advanced Research Center (HARC) to make the Pierce Marsh study data available through the National Biological Inventory Infrastructure (NBII) and the HARC websites. This partnership has culminated in an intertactive map of the sample sites, complete with site photos and dominant plant species, for this study and a parallel study on stress biomarkers, currently posted on the HARC website (http://maps.harc.edu/Marshes/). Also through this partnership, the data has been incorporated into a database, that when complete, will be availbale for public use through the National Biological Informational Infrastructure (NBII) program through HARC.

## Literature Cited

Biber, P.D. 2007. Evaluating a chlorophyll content meter on three coastal wetland plant species. J. Agricul. Food Environ. Sci. 1(2):1-11.

Brower, J.E. J.H. Zar, and C.N. Von Ende. 1998. Field and laboratory methods for general ecology, 4thed. McGraw-Hill, Boston.

Dawson, J. 2003. Watkins Properties 'harbors' big plans for Hitchcock land. Houston Business Journal. http://www.bizjournals.com/houston/stories/2003/04/14/ newscolumn4.html

Edwards, K.R., and C.E. Proffitt. 2003. Comparison of wetland structural characteristics between created and natural salt marshes in southeast Louisiana, USA. Wetlands 23(2):344-356.

Feagin, R.A. and X.B. Wu. 2006. Spatial pattern and edge characteristics in restored terrace versus reference salt marshes in Galveston Bay. Wetlands 26(4):1004-1011.

Galveston Bay Foundation. 2003. Final Report to USFWS; Pierce Marsh 1999 through 2001.

Galveston Bay Foundation. 2008. Final Report to USFWS; Agreement 1448-20181-05-G924 (Pierce Marsh Beneficial Uses Restoration Project).

Krebs, C.J. 2001. Ecology: the experimental analysis of distribution and abundance. Addison Wesley Longman, Inc., San Francisco, CA. 695 pp.

Minello, T.J. 2004. A habitat-use model to determine essential fish habitat for juvenile brown shrimp (*Farfantepenaeus aztecus)* in Galveston Bay, Texas. Fishery Bulletin, April 2004.

Minello, T.J. and J. Webb. 1999. Page 108 in Lester, J and L. Gonzalez, eds., State of the bay: a characterization of the Galveston Bay ecosystem, 2nd Edition. Galveston Bay Estuary Program Publication GBEP T-7.

Rozas, L.P., Caldwell, P., and T.J. Minello. 2005. The fishery value of salt marsh restoration projects. J. Coastal Res., Special Issue No.40: 37-50.

Rozas, L.P. and T.J. Minello. 2001. Marsh terracing as a wetland restoration tool for creating fishery habitat. Wetlands 21(3):327-341.

Thayer, G.W., T.A. McTigue, R.J. Salz, D.H. Merkey, F.M. Burrows, and P.F. Gayaldo. 2005. Science-based restoration monitoring of coastal habitats. NOAA Coastal Ocean Program Decision Analysis Series No.23, Vol.2.

Ward, G.H., and N.E. Armstrong. 1992. Ambient water and sediment quality of Galveston Bay: present status and historical trends. Galveston Bay National Estuary Program Report GBNEP- 22. 181 pages.

Whaley, S.D. and T.J. Minello. 2002. The distribution of benthic infauna of a salt marsh in relation to marsh edge. Wetlands 22(4):753-766.

White, W.A., T.A. Tremblay, E.G. Wermund Jr., and L.R. Handley. 1993. Trends and status of wetland and aquatic habitats in the Galveston Bay System, Texas. Galveston Bay National Estuary Program, Report GBEP-31. 225 pp.