Final Report

Science Based Monitoring of Created 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

Contract Number: 07-005-11

University of Houston Clear Lake

GALVESTON BAY FOUNDATION

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November 10, 2008

Introduction

Coastal marsh ecosystems in Galveston Bay and along the upper Texas Gulf coast are understood to be 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 plants are quite hearty and 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 losses have 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 ten 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, 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).

This study examined whether functional differences are achieved through different marsh restoration techniques. The study area, Pierce Marsh, is composed 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 have become 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 over the past decade.

Restoration of low marsh began in 1999 and has proceeded as funds have been available through 2006. A primary reason for choosing Pierce marsh as a 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 examining restoration projects located more distally and subject to different environmental factors (i.e., salinity regimes, sediment regimes, etc.). Restoration techniques within Pierce include an assortment of methods, primarily centered around 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.

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

1. Grid terraces (PRC2 and GRD): constructed in 1999; 153 terraces in a 63-acre area

2. Sinusoidal terraces (PRC3 and 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 (PRC4 and ZIG): constructed in 2004; 49 terraces within a 25-acre area
4. Beneficial uses marsh (PRC5 and 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 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).

This research 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. Additionally, a fifth site within Pierce Marsh was sampled for comparison against the control and restored sites for the purpose of assessing what the net value of restoring a site might be when losses from converting shallow open water to marsh are taken into account; this site has subsided and is currently shallow, unvegetated, open water and has been targeted for future restoration. Function of each study site was assessed by examining the sediments (component analysis), macrobenthic community composition, and plant density and biomass. Additionally, the study corresponds to a parallel study examining plant biomarkers of health and microbial community composition in these same restoration sites.

The specific objectives of this study were to

1. Compare four 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
        i. Chlorophyll
        ii. Root and shoot biomass
        iii. Leaf metrics
    c. Benthic macroinvertebrate community composition
2. Compare the abiotic components important to function in the same four restoration sites and reference site within Pierce Marsh by measuring the
    a. Sediment component texture
    b. Macronutrient content of the sediments
    c. Heavy metal contents of the sediments
3. Examine the net benefit of a restoration project by examining the biotic and abiotic factors above at an unrestored, subsided, shallow open-water site targeted for future restoration within Pierce Marsh.

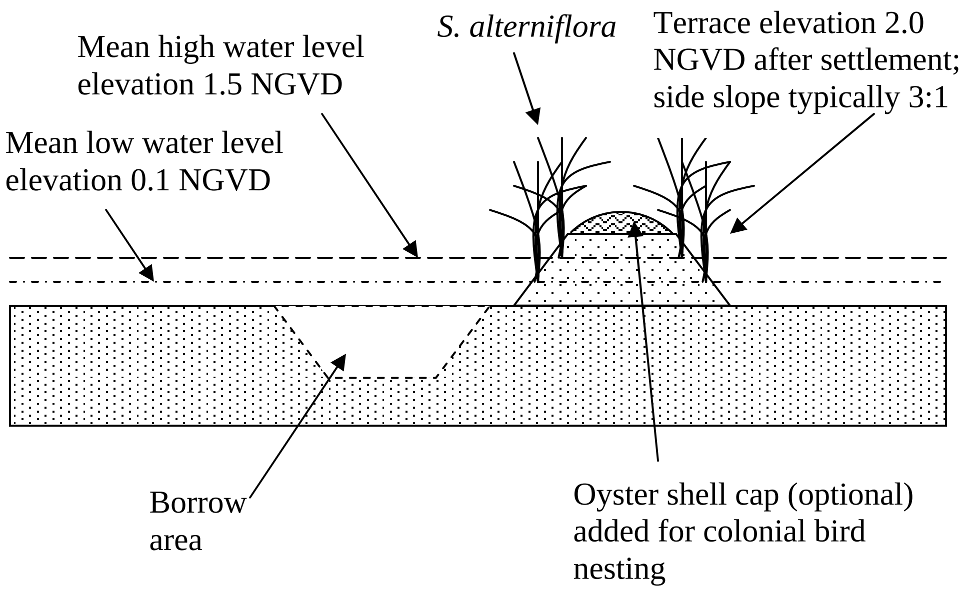

Figure 1. Cross sectional view of typical terraces constructed at Pierce Marsh. Water level elevations are determined from via bathymetric survey. Typical terrace elevations and water levels are given in National Geodetic Vertical Datum (NGVD). Terraces were constructed with a 3:1 side slope using material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

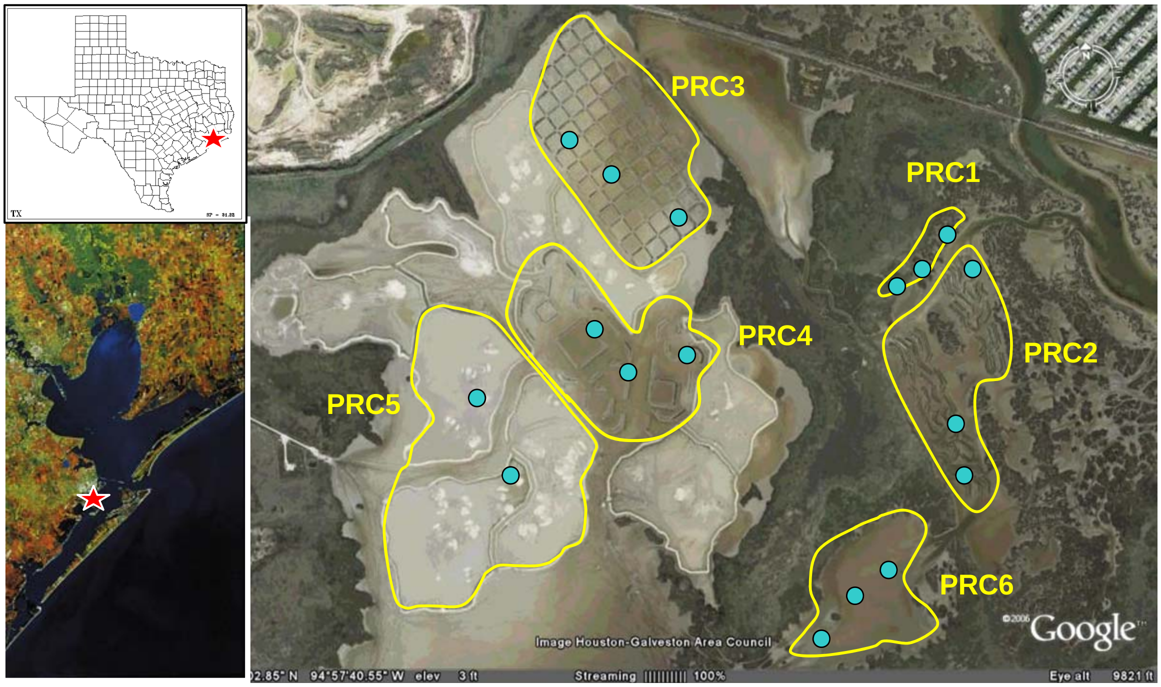

Figure 2. Aerial view of Pierce Marsh complex showing the locations of the reference site (PRC1), four restoration sites (PRC2-5), and open water site (PRC6).

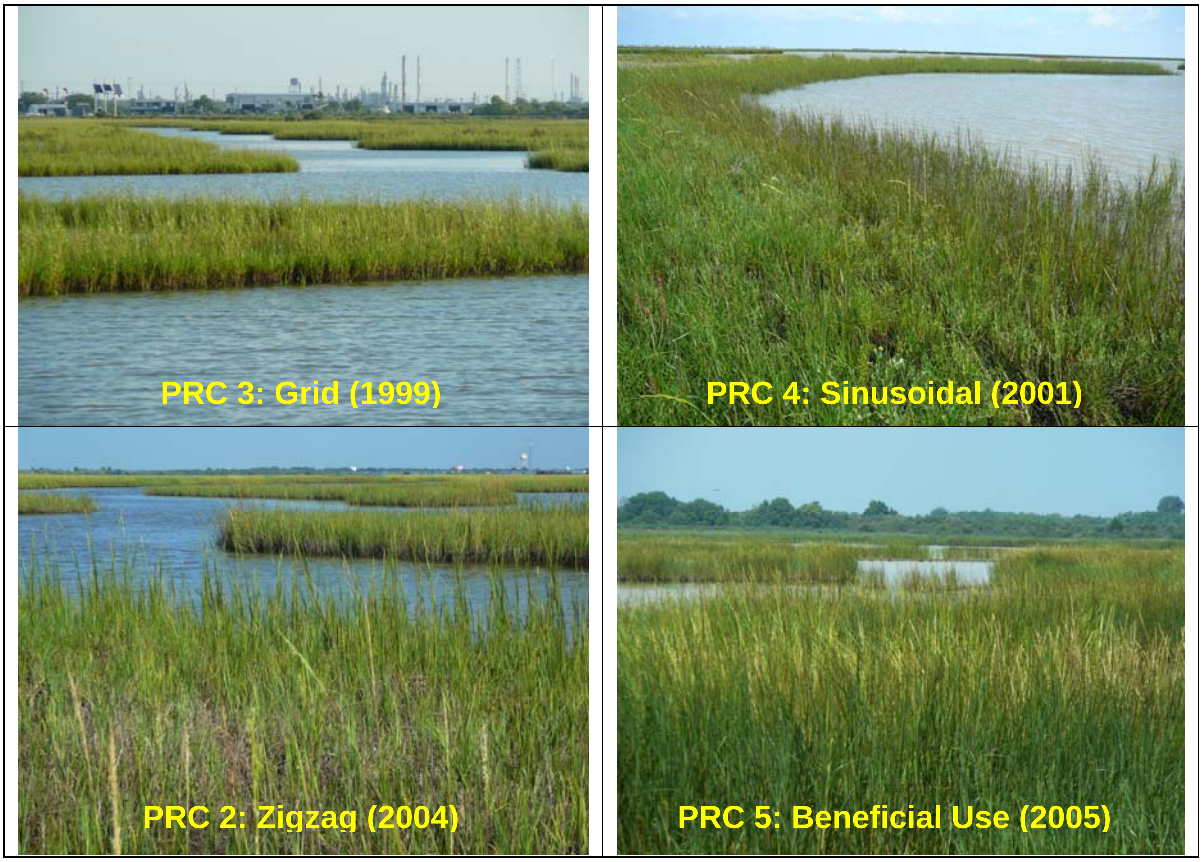

Figure 3. Photographs of the four designs used to restore marsh habitat in the Pierce Marsh complex, with dates the sites were constructed and planted with *S. alterniflora.*

Methods and Materials

Site selection

An aerial map of the Pierce Marsh complex was 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).

Field sampling

The Pierce Marsh reference, open water and restoration sites were sampled in August/September 2007 and July/August 2008. Access to the sampling areas was provided by airboat or outboard.

Transects were established at the reference (REF) site by setting the origin close to the marsh edge and recording the GPS coordinates, then extending a line 20 meters into the marsh, perpendicular to the edge. Three stations were established 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 were established at the restored sites (GRD-grid, SIN-sinusoidal, ZIG-zigzag and BUM-beneficial use material) by setting the origin at the edge of one side of the berm and recording the GPS coordinates, then extending a line 20 meters across the berm to the edge on the other side. Three stations were established 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).

Water samples were collected from Station 1 at each transect. Salinity, temperature and total dissolved solids were measured using a Hach SensION5® meter, and pH was measured with an Extech waterproof pH meter. Nitrate, nitrite, ammonia, phosphate and turbidity analyses were conducted in the UHCL laboratory within 24 hours of sample collection using standard Hach Company methods for the DRL890 colorimeter. As there were no significant differences among any of the water quality parameters measured within the Pierce Marsh complex during this study, these parameters were omitted from the data analysis.

Sediment core samples were collected for macronutrient, grain size, heavy metal and benthic macroinvertebrate 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 bag, 10% buffered formalin was added to the benthic samples, and 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. Five additional shoots of *S. alterniflora* were collected randomly from within three meters of the station and the following metrics were recorded for each plant: shoot length; number of leaves; youngest leaf length, width, thickness and chlorophyll comparison index (Minolta SPAD 1500); oldest living leaf width, thickness and chlorophyll comparison index. All leaves were then removed from the stalk, 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.

<u>Laboratory analyses</u>
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 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.

<u>Analysis of data</u>
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 and benthic community data (dependent variables). Regression analyses were used to find significant relationships ($p \leq 0.05$) among the *Spartina* metrics and sediment chemistry data. All statistical analyses were conducted using Minitab v.15 software.

Results and Discussion

Within the Pierce Marsh complex, an undisturbed reference site (REF), four restoration sites (GRD, SIN, ZIG and BUM) and an open water site (OPN) that may someday become a restored marsh site were all studied in this project. At each site, sediment and plant material from three stations along each of three transects were collected in 2007 and 2008 (a total of nine stations per site per year). This study was designed as a pilot for future monitoring and analysis of the different restoration designs in Pierce Marsh.

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 eight years) and the actual design strategy.

Sediment characteristics

Grain size varied significantly among the sites (Fig. 4). The reference (REF) and open water (OPN) sites were most similar in composition at about 45% clay, 35% silt and 20% clay. The restored sites varied between 40 and 60% clay composition; the 60% clay content of the grid terrace (GRD) stations was significantly higher than that of any of the other sites.

Macronutrient (N, P and K) concentrations were significantly higher ($p \leq 0.05$) in sediment from the REF marsh than from any of the restored sites, but did not vary significantly among the restoration sites or between them and the open water site (Fig. 5).

Similarly, concentrations of selected heavy metals (copper, chromium, cadmium, nickel and lead) were elevated significantly ($p \leq 0.05$) in the REF marsh sediments compared to the other sites (Fig. 6). Heavy metal levels also appeared to increase with the age of the restored site, driven primarily by changes in lead levels.

Benthic macroinvertebrate community

There were no significant differences in benthic macroinvertebrate community abundance, richness or diversity recorded between the REF and restored sites in Pierce Marsh from the samples collected for this pilot study. Very low numbers of organisms were collected in each 2x4-inch core sample, which made comparison among the sites virtually impossible. Due to our inability to effectively evaluate the benthic community parameters in the present study, we were also unable to make a good comparison on the ecological productivity between the open water and vegetated sites. In a future study of this marsh complex, a different sampling device (e.g., an Ekman grab) or additional replicates will be employed to maximize our ability to evaluate true differences in benthic infauna among the stations and sites.

Plant community

Total plant coverage was significantly higher ($p \leq 0.05$) in the REF marsh (70%) than in the restored sites (35-50%), with coverage in the ZIG site just half of that found in the REF site (Fig. 7). Total coverage at GRD, SIN and ZIG was negatively affected by the absence of *S. alterniflora* at the berm midpoints (Station 2) at each of these sites. Coverage by *S. alterniflora* ranged from 10% (ZIG) to 50% (BUM) and was more dependent on restoration design than by site age.

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). Shoot length of *S. alterniflora* at BUM was significantly higher than at REF or any of the other sites (data not shown); the larger plants and higher biomass could be the result of the fast growth of young *Spartina* and/or possibly a different ecotype. We currently are investigating ecotypic variation in *S. alterniflora* from sites throughout Galveston Bay in a parallel project and will be able to address this factor soon.

One of the most striking results of this study was the difference in *S. alterniflora* root biomass: root biomass in *Spartina* from the REF marsh was between 3 (ZIG) and 15 (GRD) 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.

An interesting relationship existed between *S. alterniflora* shoot density and the sediment macronutrient concentrations (Fig. 9). Total macronutrient concentrations (including N, P and K) in the sediments at all of the sites were inversely related to the shoot density at the site ($p \leq 0.05$). This may be explained in one of two ways. The nutrient content of sediments from the REF and older restored sites (GRD and SIN) was significantly higher than that of the newer sites (ZIG and BUM), due in part to the natural accumulation of nutrients that would be expected as a site ages. On the other hand, the *S. alterniflora* shoot densities were significantly higher at ZIG and BUM; the increase in plant density might be expected to result in the translocation of nutrients from the sediment to the vegetation.

One of the most important measures of success of a plant community is its level of primary productivity. For the Pierce Marsh project, chlorophyll *a* was calculated from the SPAD measurements taken on individual *S. alterniflora* leaves in the field (Chl *a* ($\mu g/cm^2$) = 3.429+0.208[SPAD]) (Biber, 2007) and primary production was calculated as 3.7mg C / hour / mg chlorophyll (Krebs, 2001). Using this approach, the average productivity for individual *S. alterniflora* plants was highest at the ZIG site and lowest at the BUM site (Fig. 10). However, combining this data with the shoot density data for each station, the most productive areas were the REF marsh and the ZIG and BUM restored sites. Although individual plant productivity was comparable to the other sites for *S. alterniflora* from GRD and SIN, the station productivity values were depressed due to low *Spartina* coverage (<15%). It is also notable that the high productivity of *S. alterniflora* at the ZIG site occurred in spite of this site exhibiting the lowest biomass values among the restored sites.

Although the lowest station *Spartina* productivity among the Pierce Marsh sites occurred at GRD, this site supported the highest number of plant species at 11, compared to the next highest richness of 6 at SIN (Figs. 11 and 12). The diversity of species inhabiting GRD included sea oxeye daisy (*Borrichia frutescens),* big-leaf sumpweed (*Iva* *frutescens*) and several others that were found at none of the other sites. Only one species, *S. alterniflora*, was recorded at BUM, although other species were noted off the transect. Five species were recorded from the REF marsh.

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 pilot study for ongoing data accumulation for these factors over a several year period. Based on this study, not one of the four restored sites is functioning at the same level as the reference site. 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). This study examined one restoration site (BUM) that 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 has been only very recently restored (2005), it is obviously still in transition. However, already it appears to be more similar to the reference sites relative to the other restoration sites by its *S. alterniflora* shoot biomass and productivity. It will be interesting 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 2008 Texas Association of Environmental Professionals Conference in Houson, Texas, and the 2008 Restore America's Estuaries Conference in Rhode Island, and will be presented at the 2008 Galveston Bay Estuary Program State of the Bay Symposium. 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.

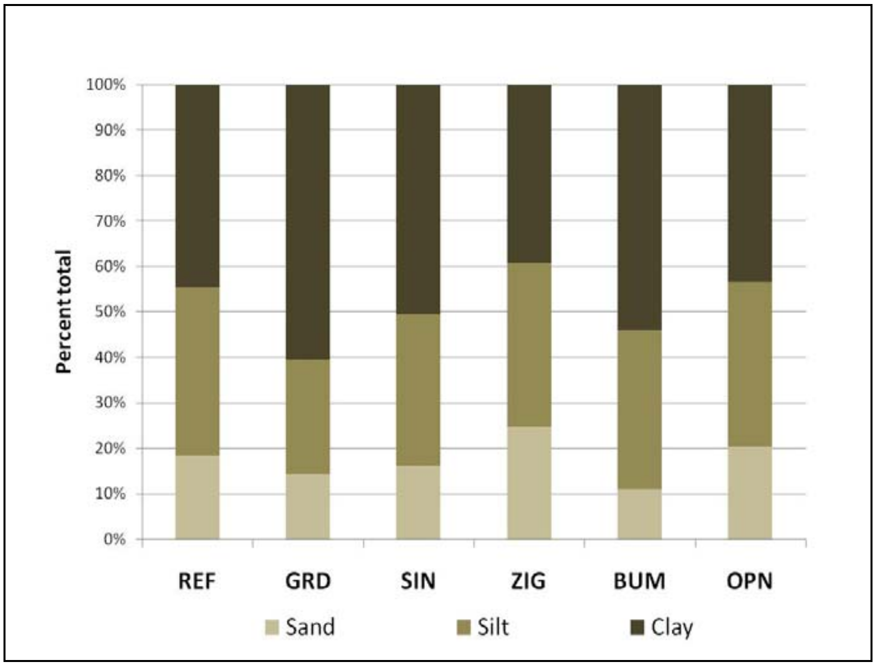

Figure 4. Comparison of sediment grain size (percent sand, silt and clay) among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material, OPN = open bottom).

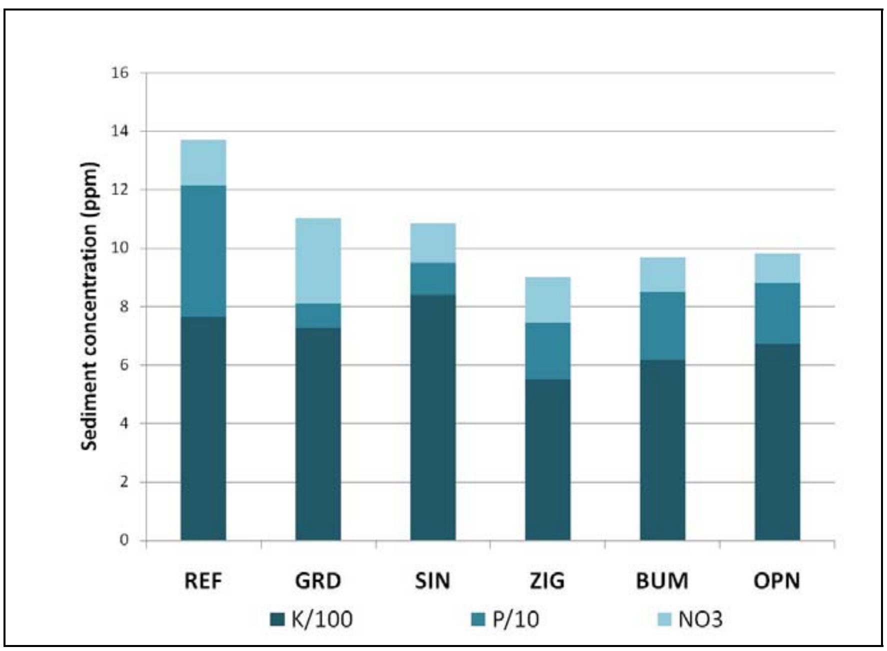

Figure 5. Comparison of sediment macronutrients (N, P and K) among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material, OPN = open bottom).

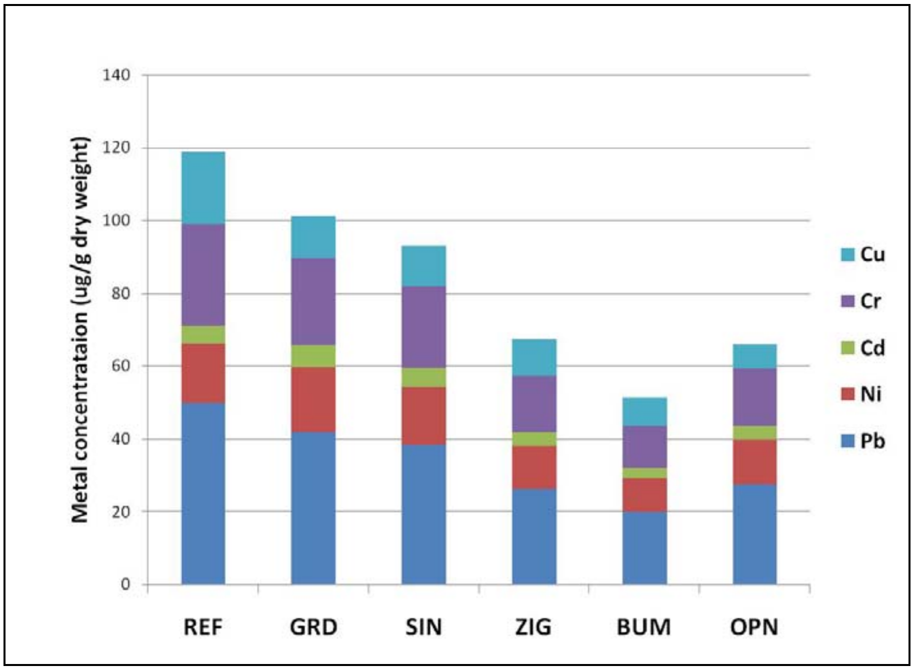

Figure 6. Comparison of selected sediment heavy metals among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material, OPN = open bottom).

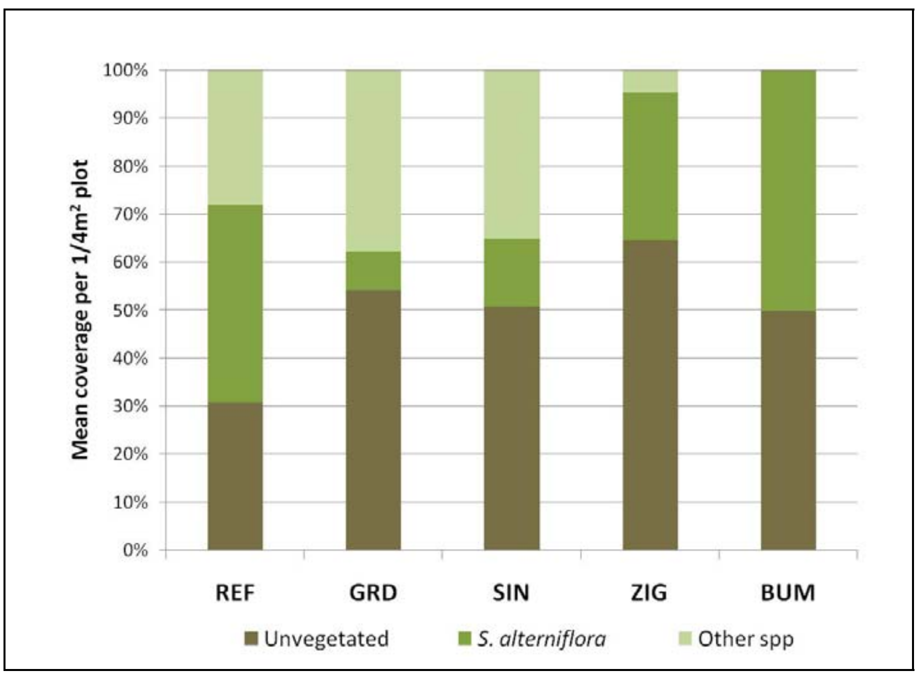

Figure 7. Comparison of total plant cover and *S. alterniflora* cover among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

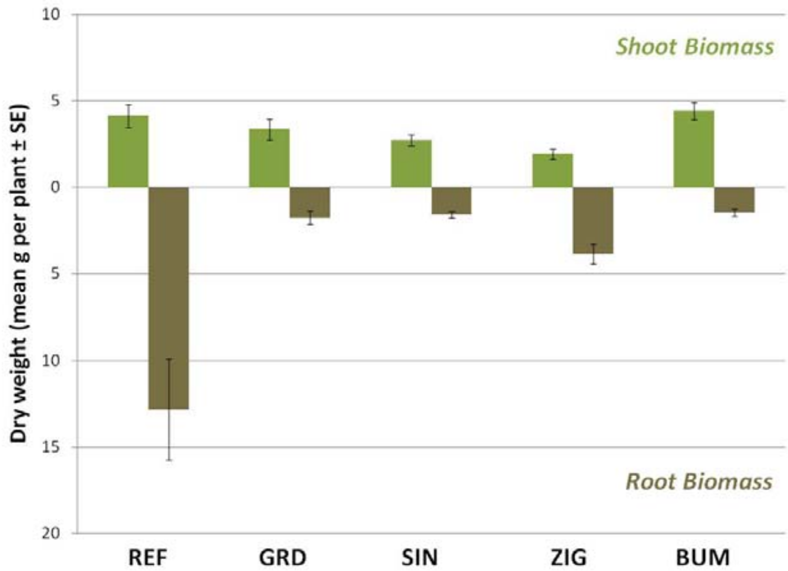

Figure 8. Comparison of shoot and root biomass of *S. alterniflora* among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

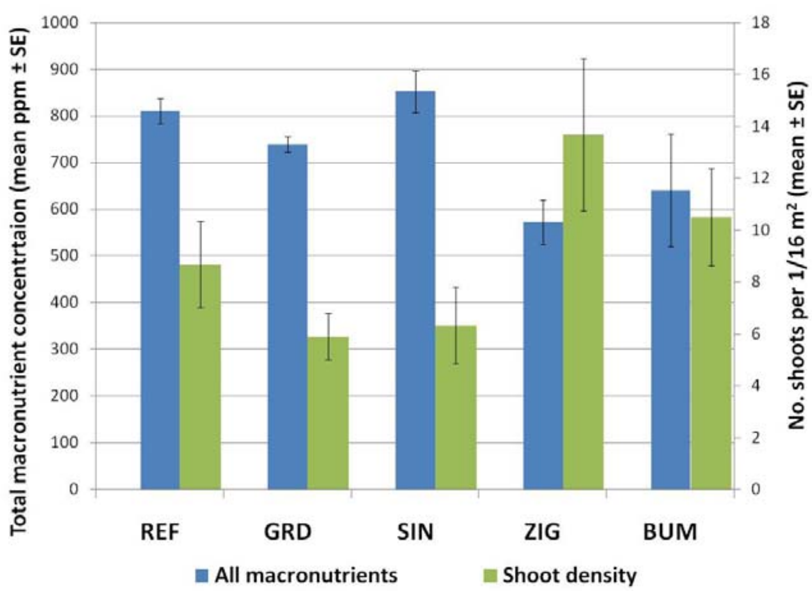

Figure 9. Comparison of sediment nutrient content and *S. alterniflora* shoot density among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

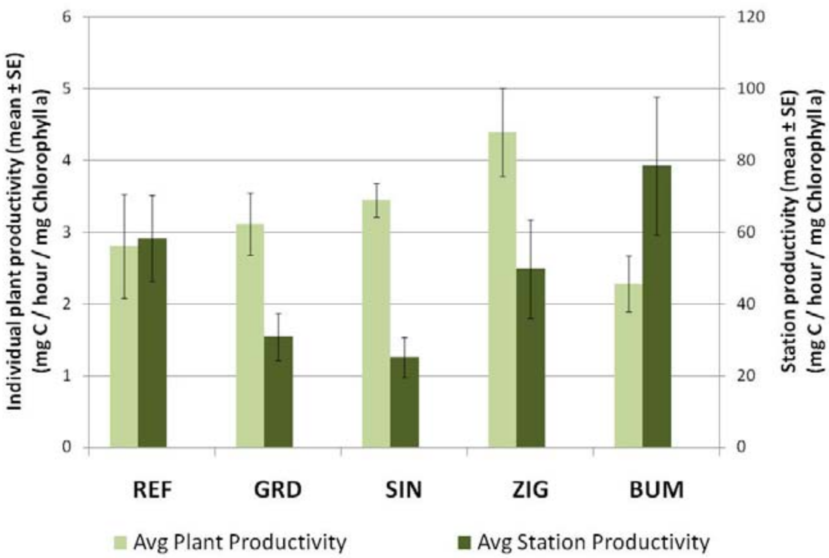

Figure 10. Comparison of individual *S. alterniflora* plant productivity and total station productivity among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

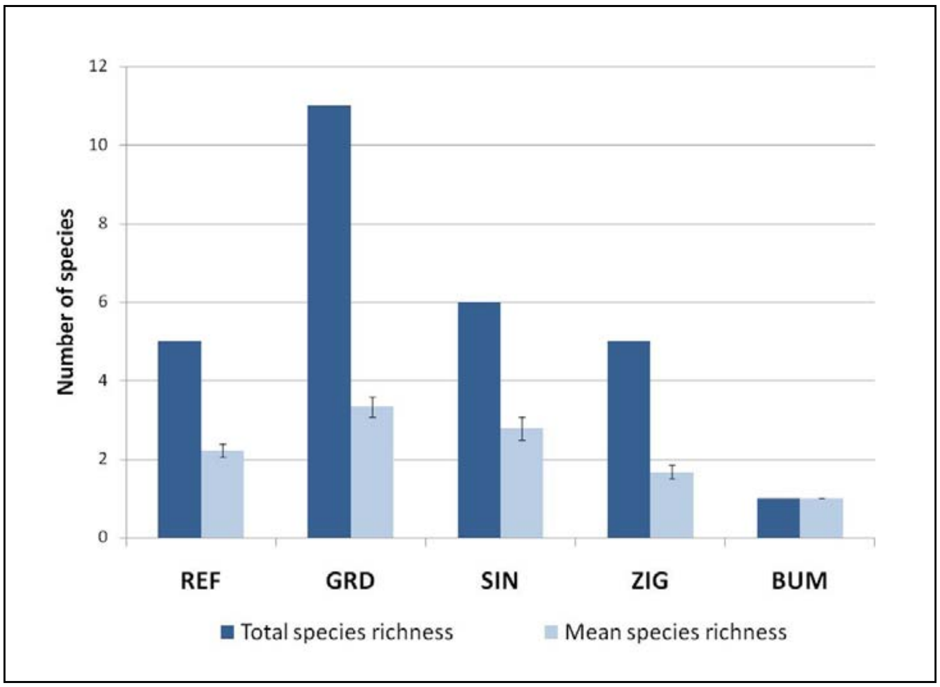

Figure 11. Comparison of plant species richness among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial use material).

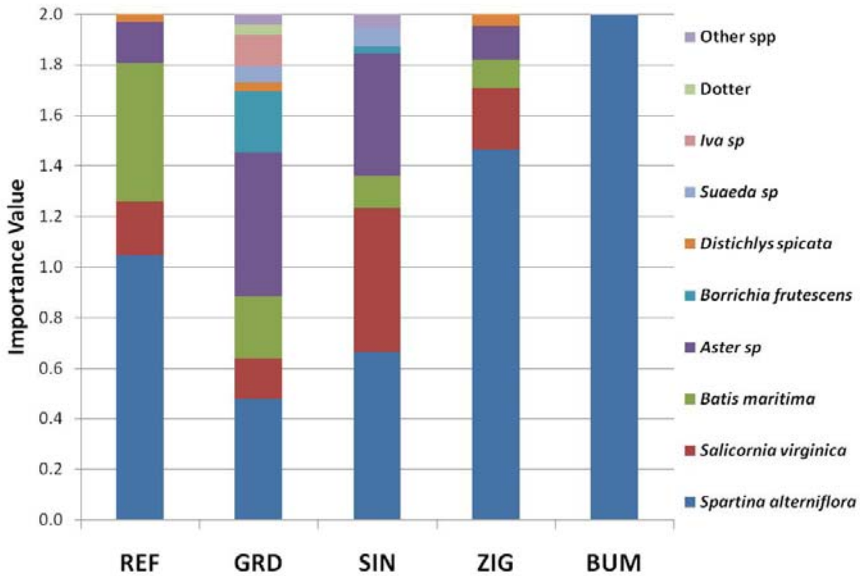

Figure 12. Comparison of plant species distributions and Importance Values (relative frequency + relative coverage of each species) among reference and restoration designs in the Pierce Marsh complex (REF = reference, GRD = grid terrace, SIN = sinusoidal terrace, ZIG = zigzag terrace, BUM = beneficial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

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