2018

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DOI: 10.18785/goms.3401.05

Recommended Citation

Loveless, J. B. and D. L. Smee. 2018. Assessing the Efficacy of Marsh Restoration via Terracing by Comparing Vegetation Density and Nekton Abundance Before and After Restoration. *Gulf of Mexico Science* 34 (1).

Retrieved from <https://aquila.usm.edu/goms/vol34/iss1/5>

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Assessing the Efficacy of Marsh Restoration via Terracing by Comparing Vegetation Density and Nekton Abundance Before and After Restoration

JACOB B. LOVELESS AND DELBERT LEE SMEE

Nueces Bay, a Texas estuary, has been heavily affected by human activities including habitat destruction, pollution, and restriction of freshwater input, leading to a loss of nearly all structured habitats in the bay. To create additional habitat and recover some lost ecosystem services, 160 acres of salt-marsh habitat were created in Nueces Bay in 2010 using marsh terracing. Mounds of marine sediment, or terraces, suitable for growth of *Spartina alterniflora*, an important foundation species in marshes, were constructed. Several volunteer events involving planting of *S. alterniflora* occurred in 2011, 2012, and 2013, allowing *S. alterniflora* to become established. The purpose of this study was to determine if this marsh restoration was effective in creating suitable habitat for estuarine species by comparing *S. alterniflora* shoot density and the faunal assemblage in the restored marsh sites to adjacent, natural marsh areas located nearby. Vegetation and associated marsh fauna were collected from the area planned for terracing and from adjacent natural marshes in 2009, before the restoration. Natural marsh and areas planned for restoration were significantly different. Vegetation was absent and animals rare in the planned restoration area before terracing. The same areas were measured in 2015 after restoration. In 2015, *S. alterniflora* was present and in densities not significantly different from nearby natural marshes. Associated marsh fauna were also not different in terms of functional group composition, species diversity, and length-to-weight relationships of individual species between natural and restored sites. The restored marsh contained similar vegetation and fauna as the adjacent natural marsh after restoration, whereas prerestoration open-water areas lacked vegetation and contained significantly fewer organisms than natural reference marsh areas. Thus, the restoration provided suitable habitat for *S. alterniflora* and associated fauna in Nueces Bay.

INTRODUCTION

Anthropogenic habitat degradation and a warming climate are causing a rapid decline in coastal marsh ecosystems worldwide. In the United States, more than half of wetland areas have disappeared over the last 200 yr (Dahl, 1990, 2011), and in the Gulf of Mexico, approximately 61% of coastal marsh wetlands were converted to open water from 1982 to 1995, accompanied by a roughly 70% decline in marsh edge habitat (transition from marsh to submerged habitats) over the same period (Rozas et al., 2007). Marsh loss can have significant impacts on estuarine faunal diversity and biomass (Minello and Rozas, 2002; Minello et al., 2008). As marsh and other coastal habitats decline, long-term negative consequences on fisheries sustainability are expected (Jordan et al., 2009). For example, over 90% of commercial fisheries production in the Atlantic and Gulf coasts consist of organisms that are dependent on wetlands for juvenile development, reproduction, and organic inputs (Chambers, 1992).

Since successful restoration of degraded habitats can help mitigate climate change and slow or reverse the loss of biodiversity (Nilsson and Aradottir, 2013), habitat rehabilitation and restoration projects have increased. Unfortunately, the success of restored habitats is often variable and poorly quantified (see Wortley et al., 2013 for review).

Marsh terracing is frequently used to restore marsh habitats (Rozas and Minello; 2007; Armitage et al., 2014). Terraces are built by taking sediment from shallow soft bottom and constructing this sediment into ridges of emergent land (Turner and Streever, 2002), and then planting native vegetation to develop a natural marsh environment. This process creates a relatively high amount of marsh edge habitat (Rozas et al., 2005), which is important because nekton heavily utilize marsh edges (Minello and Rozas, 2002). Other benefits of marsh terracing are that it can enhance fishery habitat in as little as 2 yr (Merino et al., 2010), and terraces are cheaper to construct than other alternative habitat building methods (e.g., hydraulic dredg-

ing, upland restructuring), making them a cost-effective coastal restoration technique that can have expeditious benefits (Rozas et al., 2005).

The increased productivity of fisheries within created marshes can return a substantial economic product, making their benefits tangible, while also providing other benefits (storm surge protection, carbon sequestration, etc.) that are harder to quantify (Minello et al., 2012). Studies indicate that marsh terracing can improve fisheries and increase nekton densities (Rozas and Minello, 2001, 2007; Able et al., 2004; Bush Thom et al., 2004; Rozas et al., 2005; La Peyre et al., 2007). In some cases, restored marshes do not achieve equal nekton densities or vegetation cover as nearby natural habitats they are constructed to emulate. However, even in these situations, the increase in marsh habitat made the constructed terraces preferable to open-water areas it replaced (Minello and Zimmerman, 1992; Minello and Webb, 1997; Rozas and Minello, 2001; Zeug et al., 2007). The annual rate of return from increased fishery production in restored terraced marshes was estimated conservatively at 4.5% (Minello et al., 2012), far greater than the maximum estimated return of 2.3% for hydraulic dredging, or the -1.2% net loss of upland restructuring. Using these numbers, Minello et al. (2012) estimated that increased fishery productivity could pay for the cost of marsh terracing in 2 decades. The goal of this study was to determine if a marsh restoration project in Nueces Bay, TX was successful in creating new marsh habitat with similar flora and fauna as adjacent natural marshes, thereby recovering some ecosystem services in terms of creating new habitat for estuarine organisms. We used common metrics that are reflective of quality habitat for marsh fauna including biodiversity and faunal abundance (Wortley et al., 2013; Zhang et al., 2015) as well as several metrics proposed by La Peyre et al. (2007) including faunal density, biomass, functional group composition, and nekton length-to-weight relationships that are reflective of habitat quality.

METHODS

Nueces Bay, TX is a microtidal lagoonal estuary that has been radically changed by human activities throughout much of the 20th century. Heavy industry on the southern shores has led to high levels of zinc and other contaminants in the Bay (Hill et al., 2014). Once home to numerous oyster reefs, nearly all the

oyster reefs in the bay were harvested and few living oysters remain. Nueces Bay is starved of freshwater, with 99% of traditional freshwater input into the bay now held in upstream reservoirs (Dunton et al. 2001). Salinity in Nueces Bay can reach more than 50 and quickly drop to 0 after heavy rains (Dunton et al., 2001). To recreate suitable habitat and recover some lost ecosystem services in Nueces Bay, a salt marsh was constructed in 2010. *Spartina alterniflora*, the most abundant marsh plant and a key foundation species, is present in fringing natural marshes in Nueces Bay, but the center of the Bay is too deep for emergent vegetation. Terraces were constructed to provide suitable tidal elevation for marsh vegetation, *S. alterniflora* in particular. Terraces were made using marine sediment from Nueces Bay and constructed to extend ~ 1.0 m above the water and provide a gentle slope to the Bay bottom. Terraces varied in size (Fig. 1), with a long terrace designed to shield smaller terraces from wave action created by frequent winds that commonly exceed 30 km hr⁻¹. After terrace construction, local volunteer groups conducted several community planting activities from 2011 to 2013 using *S. alterniflora* plants transplanted from local estuaries onto the newly constructed terraces. *Spartina alterniflora* planted by volunteers was not carefully monitored and plant density varied among individual volunteers. *Spartina alterniflora* was, however, planted at similar tidal elevations on terraces as found in natural fringing marshes.

Because salinity in Nueces Bay is highly variable, we assessed restoration efficacy by comparing natural reference marshes with the area of restoration before and after terrace construction. Thus, we did not compare associated fauna before vs after restoration because in this study area, large variation in abiotic conditions would require many years of sampling pre- and postrestoration to clearly document overall changes in the Bay. Rather, our goal was to determine if the restored area was or was not similar to adjacent natural areas when measured under the same conditions.

All vegetation and faunal surveys in this study were conducted on 19 Aug. 2009 and 4 Sep. 2015 adjacent to the Portland Causeway in Nueces Bay, TX (Fig. 1). In 2009, 10 sites in the area slated for restoration were sampled for vegetation and fauna and were compared with 10 natural reference marsh sites located nearby (20 sites total). In 2015, 20 sites were again sampled, 10 from the restored area and 10 from natural

Fig. 1. Map of sampling location in Nueces Bay, TX with natural (X) and restored (O) sites indicated.

reference marsh sites (Fig. 1). Sites were at least 100 m apart and haphazardly sampled using a throw trap. The throw trap consisted of a 1-m² aluminum frame surrounded in mesh that is inserted into the substrate to prevent nekton from escaping. Once secured, a seine was dragged across the bottom of the throw trap to remove all organisms from within the trap. Seining commenced until three consecutive drags yielded no organisms. Organisms were placed in 95% ethanol and transferred to Texas A&M University-Corpus Christi where they were sorted, weighed, enumerated, and identified to the lowest possible taxon. The number of *S. alterniflora* stems inside the 1.0-m² throw trap was counted to quantify density. *Spartina alterniflora* in all marsh sites were submerged during sampling to depths ranging from 0.4 to 0.6 m. Water quality was measured using a Hydrolab data sonde. In 2009, salinity was 43.9 parts per thousand (ppt), dissolved oxygen was 10.9 mg/liter, turbidity was 214.2 nephelometric turbidity units (NTU), and pH was 8.4. In 2015 salinity was 17.5 ppt, dissolved oxygen was 8.3 mg/liter, turbidity was 10 NTU, and pH was 7.9.

Statistical analysis.—Abundance data collected in 2009 was compared between natural marsh and open-water sites where restoration was planned

using the multivariate analyses ANOSIM and SIMPER with the statistical software PRIMER[™]. No other metrics were compared because of the near absence of organisms collected in open-water sites. For 2015 data, all organisms collected were used in the comparison of community structure by performing ANOSIM and SIMPER analyses, and multidimensional scaling (MDS) plots were also constructed in PRIMER. The biomass in grams, density in square meters, and length-to-weight relationships of the four most prevalent species [grass shrimp (*Palaemonetes pugio*), brown shrimp (*Farfantepenaeus aztecus*), blue crab (*Callinectes sapidus*), and naked goby (*Gobiosoma bosc*)] as well as *S. alterniflora* stem density were also analyzed in SAS[™]. SAS Proc GLM was used to perform multivariate ANOVAs (MANOVAs) to test *S. alterniflora* stem density, biomass, species density, and length-to-weight relationships of the four most common species in natural and restored marshes. Data were log transformed to meet MANOVA assumptions.

RESULTS

In 2009 grass shrimp were absent in open-water sites (that were later to be restored), and few organisms were collected. Only 28 individuals were collected: 21 penaeid shrimp, 2 gobies,

TABLE 1. SIMPER analysis for nekton in natural and open-water areas before restoration (where terraces were constructed). Densities (m^2) shown were square-root transformed for analysis.

Species	Natural Mean abundance	Open water Mean abundance	Natural vs open water	
			Dissimilarity	% Contributed
Grass shrimp	5.92	0	52.25	57.47
White shrimp	2.07	0.73	15.63	74.67
Average dissimilarity = 90.91				

and 5 juvenile blue crabs. In contrast, natural sites were dominated by grass shrimp, making up 83% of the 518 individuals collected. Fish were rare in both natural marsh ($n = 14$) and open-water ($n = 2$) areas, contributing less than 3% of organisms collected. Nekton communities within the natural marsh and open-water sites were significantly different by ANOSIM ($R = 0.41$, $P = 0.001$), and SIMPER analysis indicated a 91% dissimilarity (Table 1) between natural marsh and open-water sites before restoration.

In 2015 grass shrimp were the dominant organism in both natural ($n = 1,083$) and restored ($n = 1,018$) sites, constituting 77% of the 2,501 individuals collected. Brown shrimp contributed the most biomass, comprising 45% of the 756.7-g total. Naked gobies were the most common fish in both natural ($n = 23$) and restored ($n = 38$) sites, with no other fish species contributing more than 0.01% to the total. MANOVA showed no significant differences in biomass ($F_{4,15} = 02.98$, $P = 0.06$), density ($F_{4,15} = 02.64$, $P = 0.08$), weight-to-length relationship ($F_{4,15} = 0.78$, $P = 0.53$), and *S. alterniflora* stem density ($F_{1,18} = 2.09$, $P = 0.17$), and post hoc testing on grass shrimp, brown shrimp, and naked gobies showed no significant differences across any of the metrics measured. Blue crab weight-to-length relationship was not significantly different; however, blue crab biomass ($F_{1,18} = 5.78$, $P = 0.03$) and densities ($F_{1,18} = 7.61$, $P = 0.01$) were significantly higher in natural sites. A metric MDS plot (Fig. 2) showed no identifiable grouping patterns, suggesting that the two marsh types were similar, and ANOSIM indicated that

natural and restored sites were not different ($R = 0.093$, $P = 0.082$). SIMPER analysis from 2015 indicated less dissimilarity (22.49, Table 2) than was found in 2009 prior to restoration (90.91, Table 1), which was consistent with findings from ANOSIM and MDS analyses.

DISCUSSION

Restoring marshes and other aquatic habitats are often performed to recover lost ecosystem services such as shoreline protection and water filtration, as well as to create habitat and increase biodiversity. Salt-marsh habitat created via terracing in Nueces Bay, TX, an estuary heavily affected by human activities, was performed to increase the abundance and diversity of marine organisms in this area. Before the restoration, no vegetation and few organisms were present in the site where restoration was planned, whereas marsh vegetation and numerous organisms could be found in adjacent natural marsh sites. After restoration, both the density of *S. alterniflora* and associated marsh fauna were not significantly different among the restored marsh and nearby natural reference marsh sites, suggesting that the restoration project was successful in providing marsh habitat for estuarine organisms.

Vegetation was not present in the restored area before terracing, and significantly fewer organisms were found there in comparison with adjacent natural marshes. Vegetation and other structured habitat are well known to provide food and predation refuges for many species, and the lack of vegetation before terracing likely contrib-

TABLE 2. SIMPER analysis for nekton in natural and restored marsh sites. Densities (m^2) shown were square-root transformed for analysis.

Species	Natural Mean abundance	Restored Mean abundance	Natural vs restored	
			Dissimilarity	% Contributed
Grass shrimp	9.51	9.31	1.04	41.3
Brown shrimp	4.02	4.2	1.41	63.99
Blue crab	2.69	1.55	1.45	84.14
Average dissimilarity = 22.49

Fig. 2. Metric MDS plot showing distances between community samples from natural and restored marsh sites.

uted to the dearth of fauna. Grass shrimp were the most abundant organisms collected in 2009 and 2015. In 2009, in the area without vegetation, grass shrimp were absent. Grass shrimp minimize their exposure to predation risks by finding refuge in marshes or other physical structures (Heck and Thoman, 1981), structures that are lacking in the soft sandy bottom that covers much of Nueces Bay. Grass shrimp also get their primary source of organic inputs by consuming microalgae growing on seagrass, marsh cordgrass, and other aquatic macrophytes (Morgan, 1980), further explaining the lack of grass shrimp found in sites without vegetation. Grass shrimp are an important food source to many estuarine and coastal wetland species (Kneib and Stiven, 1982; Anderson, 1985), providing an invaluable avenue for energy transfer up trophic levels and enhancing fisheries (Anderson, 1985). Thus, the lack of useable habitat and no grass shrimp to provide a base for the food web are the likely causes for the low number of organisms collected in open-water areas in 2009.

In 2015, the natural and restored marshes surveyed contained similar densities of *S. alterniflora*, and their respective nekton communities were not significantly different. Thus, the area before restoration lacked vegetation and had significantly fewer organisms than adjacent

natural areas, but these differences were not found after terracing and *S. alterniflora* planting. These observations suggest that the restoration increased marsh habitat for species in the estuary. Structural elements of restored salt marshes (e.g., vegetation) can establish quickly in the right conditions (Kneib and Stiven, 1982; Edwards and Proffit, 2003), and *S. alterniflora* density was not different among natural and restored areas after the restoration was complete. Since *S. alterniflora* density was not different between natural and restored areas, the similarity of nekton communities in natural and restored sites is likely explained by new marsh vegetation providing similar foraging opportunities and refuges from predation.

Previously, restored marshes were found to have similar blue crab densities and biomass when compared with reference sites (Minello and Zimmerman, 1992; Jivoff and Able, 2003); however blue crabs were more abundant with more total biomass in natural sites in this study. These metrics were the only significant differences between natural and restored areas. However, the blue crab length-to-weight relationship, which is reflective of blue crab health (Vila-Gispert and Moreno-Amich, 2001; La Peyre *et al.*, 2007), was not significantly different. This suggests that even though there were fewer crabs

in the restored sites, the crabs were growing in a similar manner, or at the least, healthier crabs did not prefer one type or the other in their migrations. This, along with the lack of significant differences found in the length-to-weight relationship of other species, suggests that restored habitat was of comparable quality with other natural areas in Nueces Bay.

CONCLUSION

Marsh terracing has been shown to be a cost-effective, highly productive method for restoring destroyed and degraded marsh habitat (Minello et al., 2008, 2012), and these findings suggest that it was effective in creating marsh habitat in Nueces Bay. By providing habitat for species on low trophic levels such as grass shrimp, this and other restorations may enhance fisheries and have positive economic impacts. Climate change and human population growth, coupled with destruction of valuable coastal habitats, will likely continue to be a serious problem. It is imperative to employ effective conservation and restoration strategies. As marsh terracing is becoming a more popular method for coastal restoration projects, monitoring its efficacy and the subsequent benefits provided from the restoration will continue to be an important area of research. The increasing volume of data supporting it as a restoration technique can be used as a tool in future natural resources management and conservation. Our findings suggest that in Nueces Bay, terracing was effective in creating additional suitable habitat for endemic species.

ACKNOWLEDGMENTS

We thank the Coastal Bend Bays and Estuaries Program for funding, and the Marine Ecology Lab at Texas A&M University-Corpus Christi for assistance with fieldwork and species identifications. We are especially thankful to Keith Johnson, James Sanchez, Philip Torres, Meredith Diskin, Pamela Parnell, Tiffany Hawkins, and Fahd Alghamdi for field assistance and Ben Belgrad for reviewing the manuscript. Finally, we thank Vincent Paul Abbott and Darrell Lance Abbott for continuing inspiration as well as S. Bock for relief after long field days.

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