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DO SMALL, PATCHY, CONSTRUCTED INTERTIDAL OYSTER REEFS REDUCE SALT MARSH EROSION AS WELL AS NATURAL REEFS?

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Abstract: One ecological service that oyster reefs provide is stabilization of shorelines through reduced wave energy and erosion from boat traffic, storms, and predominant wind direction. Additionally, increasing sedimentation can enhance the growth of emergent marsh vegetation which further stabilizes unconsolidated sediments. A 21 mo study of constructed (with only 30-35% coverage) and natural oyster reefs in 3 bayous in the Grand Bay National Estuarine Research Reserve (NERR) suggested constructed reefs benefit this retrograding deltaic ecosystem. The marsh edge adjacent to all constructed reefs was less eroded (mean = 0.043 m) than edges adjacent to natural reefs (mean = 0.728 m), although all natural and constructed sites, regardless of bayou, illustrated large variations in marsh edge growth. The marsh edge in constructed sites in one bayou retreated more than in the other bayous, most likely due to its coarser sediments, greater boat traffic, and its apparent higher energy location within the landscape. By the end of this study, the ecological function of constructed oyster reefs in all bayous, as measured by marsh edge erosion reduction, was equivalent or exceeded the function in nearby natural oyster reefs. The physical structure of the reef further served to reduce erosion and marsh loss and this approach may be useful for management of a retrograding deltaic estuarine ecosystem like the Grand Bay NERR.

Introduction

Eastern oyster, *Crassostrea virginica*, reefs once thrived in the coastal environments of the Atlantic and Gulf of Mexico (GOM) but have declined as a consequence of overharvesting and environmental degradation, exacerbated by disease, epizootics, and altered water flow (Breitburg et al. 2000, Coen and Luckenbach 2000, LaPeyre et al. 2003). This loss has not only resulted in diminished harvestable oysters but also plays an important role in the overall degradation of estuaries. Oyster reefs provide fundamental biological, physical, and chemical functions (Rodney and Paynter 2006, Coen et al. 2007, Nestlerode et al. 2007; Beck et al. 2009) that contribute to the persistence of estuarine ecosystems. Because of the economic and ecological value of this specialized habitat, projects have been conducted at multiple scales to restore subtidal and intertidal oyster reefs to their historical extent. Data on fringe (Cake 1983; hereafter referred to as small), intertidal reefs suggest that they provide unique and necessary habitat for resident and transient estuarine fauna as well as shoreline stabilization (Meyer et al. 1997, Bartol and Mann 1999, Meyer and Townsend 2000, Piazza et al. 2005).

The three–dimensional structure of oyster reef habitat, with its high surface area and abundant interstitial space, enhances the value of a reef by: 1) encouraging the settlement of oyster spat and other sessile organisms that promote the growth and physical expansion of the habitat (Tolley and Volety 2005, Rodney and Paynter 2006, Powell and Klinck 2007, Gregalis et al. 2008, Gregalis et al. 2009); 2) attracting a diversity of infaunal and epifaunal organisms (Powers et al. 2003, Tolley and Volety 2005, Shervette and Gelwick 2008a); 3) increasing prey biomass available to predators, thereby enhancing trophic transfer (Meyer and Townsend 2000, Tolley and Volety 2005, Rodney and Paynter 2006); 4) providing a shallow water refuge in times of stress, such as desiccation stress and seasonal hypoxia (Lenihan et al. 2001) or parasite infestation (LaPeyre et al. 2003); and 5) creating physical barriers that enhance sediment deposition and buffer wave energy, thus increasing marsh area and reducing shoreline erosion (Meyer et al. 1997, Piazza et al. 2005, Coen et al. 2007). These functions become compromised with the large–scale loss of oyster reefs (Hargis and Haven 1999, Boesch et al. 2001, Beck et al. 2009).

Although oyster reefs are an ecologically and economically valuable estuarine habitat type, few studies have focused on restoration of and ecological services provided by small, intertidal reefs that thrive in the shallow estuaries along the GOM (Piazza et al. 2005, Tolley et al. 2005, Shervette and Gelwick 2008a, b). As part of a larger restoration project

(Peterson and Stricklin 2008), we examined one ecological service of oyster reefs, marsh edge vegetation stabilization and growth, within three bayous of the Grand Bay National Estuarine Research Reserve (NERR), located in southeast Jackson County, Mississippi. We tested the hypothesis that small, intertidal constructed oyster reefs have similar or enhanced shoreline protection capability as nearby natural reefs.

Materials and Methods

Site description

Replicate sites in intertidal areas were selected to construct oyster reefs and examine shoreline change based on adjacent available oyster habitat, water flow, salinity, substrate, and slope suitable for natural seeding and development of self–sustaining reefs (Cake 1983) in three bayous of the Grand Bay NERR (30°23'N, 88°24'W): Bayou Cumbest, Crooked Bayou, and North Rigolets (Figure 1). Grand Bay NERR is a marine dominated ecosystem (Peterson et al. 2007) with freshwater input occurring via precipitation, runoff, and inflow from Bayou Cumbest. Tides are microtidal (~0.5 m) and can be wind–driven. The Grand Bay NERR is a retrograding delta with marsh erosion rates ranging from 0.5–4.0 m/yr, with much of the system experiencing rates of > 2.5 m/yr (Otvos 2007). Bayou Cumbest is the farthest inland of the three bayous with a well–consolidated clay and sand shore adjacent to a steep, upland erosional marsh edge consisting of *Spartina alterniflora* and *Juncus roemarianus*. Crooked Bayou is the middle bayou with a poorly consolidated muddy bottom, and is adjacent to *S. alterniflora*. North Rigolets is located between Point aux Chenes Bay and Middle Bay, is composed of unconsolidated mud, and is adjacent to *S. alterniflora*.

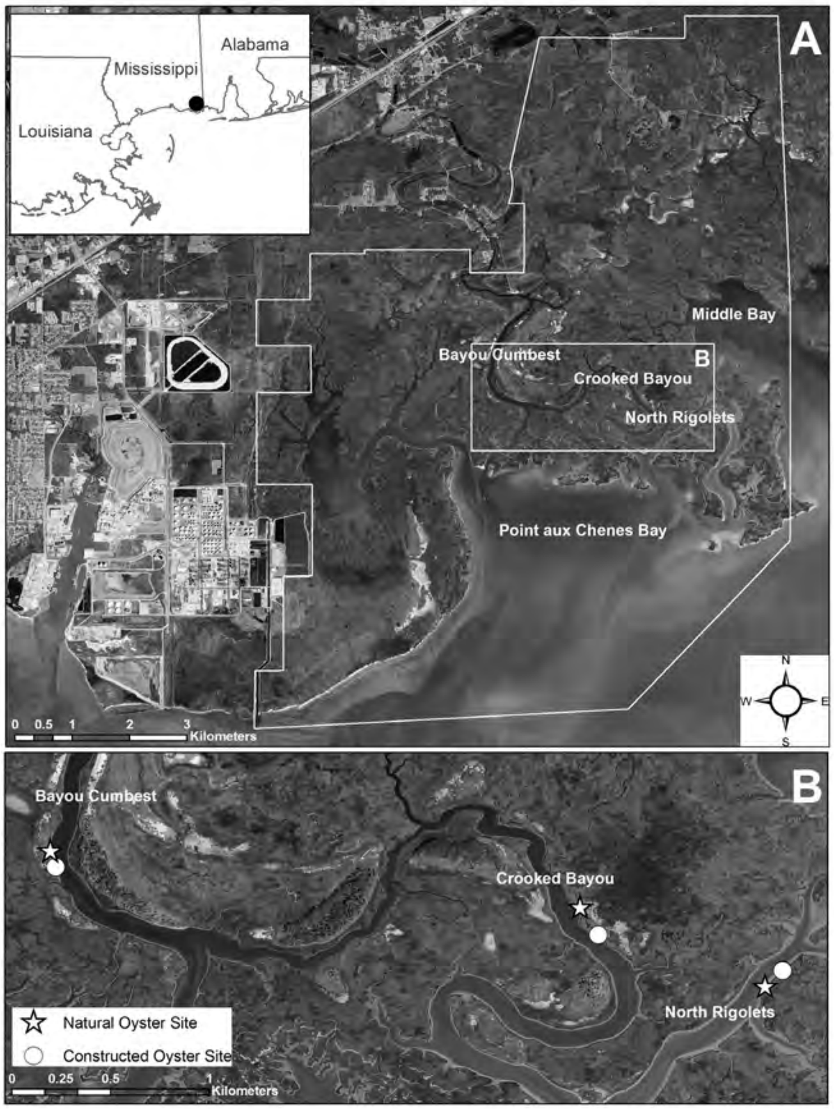

Figure 1. *Sampling sites. A. Map of the Grand Bay National Estuarine Research Reserve, Jackson County, MS and the three bayous sampled. B. Close-up of the locations of the constructed and natural oyster reef pairs in the three bayous.*

Reef construction and sampling procedures

Within each bayou, we constructed 55.8 m^2 (30.5 m x 1.8 m) intertidal oyster reefs on 17–18 August 2006, and each was set at least 92 m away from a paired nearby natural reef. Each paired set was subject to similar physical conditions within each bayou, and each reef location (constructed or natural) was divided into 3 contiguous sections which served as replicates. Within each of these sections, an equal-sized grid of cells was visualized to facilitate the placement of trays (48.26 cm L x 30.48 cm W x 11.43 cm H; Norseman Plastics) with shell bags and/or shell bags alone (max mesh size = 25.4 mm; same dimensions as trays) during initial reef construction. To simulate the observed patchiness in natural reefs, the constructed reefs were supplemented with shell bags or trays with shell bags (see Peterson and Stricklin 2008 for details on biological assessment component) filled with about 0.03 m^3 (1 ft^3) of oyster cultch to reach the desired 30–35% coverage (a total of 34 bags and trays per section). Shell bags were laid flat on top of the mudflat and trays were dug into the mudflat to be no higher than shell bags, but both were about 15 cm (6 in) above the mudflat. The trays with shell bags and shell bags were deployed in the intertidal zone between high and low tide, and bags were cut open to mimic natural habitat.

The ability of oyster reefs to enhance marsh edge stabilization and growth was assessed using marsh edge stabilization profiles (Meyer et al. 1997). A midline transect on each natural and constructed reef replicate section (n = 3) was established with a PVC stake in the marsh

TABLE 1. *Summary of water quality conditions pooled over the course of the study (χ ± 1 se). There were no significant differences among bayou or habitat for any variable over the course of the study.*

Bayou	Habitat	Temp (°C)	Salinity	DO (mg/L)
Bayou Cumbest	Constructed	20.23 ± 2.67	20.87 ± 2.16	7.02 ± 1.21
	Natural	20.45 ± 2.64	21.33 ± 2.12	5.70 ± 0.61
Crooked Bayou	Constructed	21.04 ± 2.31	24.16 ± 1.63	6.46 ± 0.96
	Natural	21.27 ± 2.41	24.29 ± 1.47	6.57 ± 0.74
North Rigolets	Constructed	19.87 ± 2.46	25.06 ± 1.59	5.81 ± 0.95
	Natural	20.02 ± 2.45	25.10 ± 1.67	5.93 ± 0.96

and a PVC stake within the water but immediately upland of the reef boundary. Marsh edge growth was measured as the change in distance (m) between the upland pole and the edge of the marsh grass along the midline transect for each pole set. We attempted to be accurate with measurements of the poles on each sampling event but there may have been some minor error in these measurements over time and space. These data were analyzed as the change in distance over time in comparison to the initial distance measured in August 2006. Monitoring was conducted quarterly over a 21 mo period from November 2006 through June 2008. Salinity, water temperature (°C), and dissolved oxygen (mg/L) were measured once per sampling event at each reef location with a YSI model 85 handheld meter.

Data analysis

Water temperature, salinity and dissolved oxygen were averaged over date and compared with a 2–way ANOVA with bayou and habitat as main effects. Results were considered significant if $p \leq 0.05$ and all data were tested for normality and homogeneity of variance prior to ANOVA. All 3 variables met these assumptions.

Marsh edge growth was examined between habitat type (natural, n = 3 and constructed, n = 3 reefs) and bayou (n = 3) (between–subjects factors) and across time (quarters, n = 7) (within–subjects factor) with a split–plot ANOVA (Green and Salkind 2008). If a significant F–value was noted for the between–subjects component of the analysis, mean values were evaluated with a post-hoc Sidak test. For the within–subject component, we adjusted the degrees of freedom with the Greenhouse–Geisser epsilon value (Field 2005, Green and Salkind 2008). Significant F–values for within–subject factors (change over time) were followed up with paired–t tests between all possible time periods, and adjusted with a sequential Bonferroni technique (Rice 1989), reducing the chance of a Type I error in making multiple pairwise comparisons. However, because Bonferroni adjustments are very conservative, we chose to balance making a Type I or Type II error by using p = 0.10; data were analyzed using SPSS (version 15.0). Results were considered significant if $p \leq 0.05$ except where noted above and all data were tested for normality and homogeneity of variance prior to ANOVA. Data for marsh edge growth were untransformed. Also, if a significant interaction term was indicated for the between-subjects main effects, the F–values and partial eta squared (partial η^2, effect size) values were compared to aid in interpreting the importance of the main effects relative to the interaction term(s). Partial η^2 is the proportion of the total variation attributable to a factor excluding the other main and interaction factors (Green and Salkind 2008). The values range from 0 to 1, with higher numbers having a greater effect size. For consistency, all interaction terms are presented in the B x H (i.e., bayou x habitat type) format. One of the marsh edge transect poles was vandalized from one constructed site in Bayou Cumbest in May 2007 limiting the analysis to only 2 replicates from that point forward.

Results

Water temperature, dissolved oxygen and salinity between bayou and habitat (constructed and natural) were similar and not significantly different ($p > 0.05$) over the course of this

TABLE 2. *Summary of split plot ANOVA statistics, the follow-up Sidak pairwise multiple comparisons (between-subjects), and paired-t tests (within-subjects). B = bayou, H = habitat, Q = reverse time (quarter), BC = Bayou Cumbest, CB = Crooked Bayou, NR = North Rigolets, C (c) = constructed, N (n) = natural. Quarter (time): 1 = November 2006, 2 = February 2007, 3 = May 2007, 4 = August 2007, 5 = December 2007, 6 = March 2008, 7 = June 2008. Bold values are significantly different within columns.*

Measure	Overall test p-value (F-value, partial η^2)	Bayou comparison (χ distance ± 1 se)	Habitat (χ distance ± 1 se)	Quarter (time)
Marsh edge distance (m)	B = 0.389 (1.031, 0.158)	BC > CB > NR	**C > N**	BCc
	H = 0.002 (17.066, 0.608)	(BC: -0.212, 0.154)	(C: -0.043, 0.122)	BCn
	B*H = 0.001 (14.353, 0.723)	(CB: -0.463, 0.138)	(N: -0.728, 0.113)	**CBc = 1>4**
	Q < 0.001 (12.988, 0.541)	(NR: -0.483, 0.138)		**CBn = 1>(6=7), 3>2**
	B(Q) < 0.001 (4.926, 0.472)			NRc
	H(Q) < 0.001 (5.274, 0.324)			NRn
	B*H(Q) < 0.001 (6.782, 0.552)			

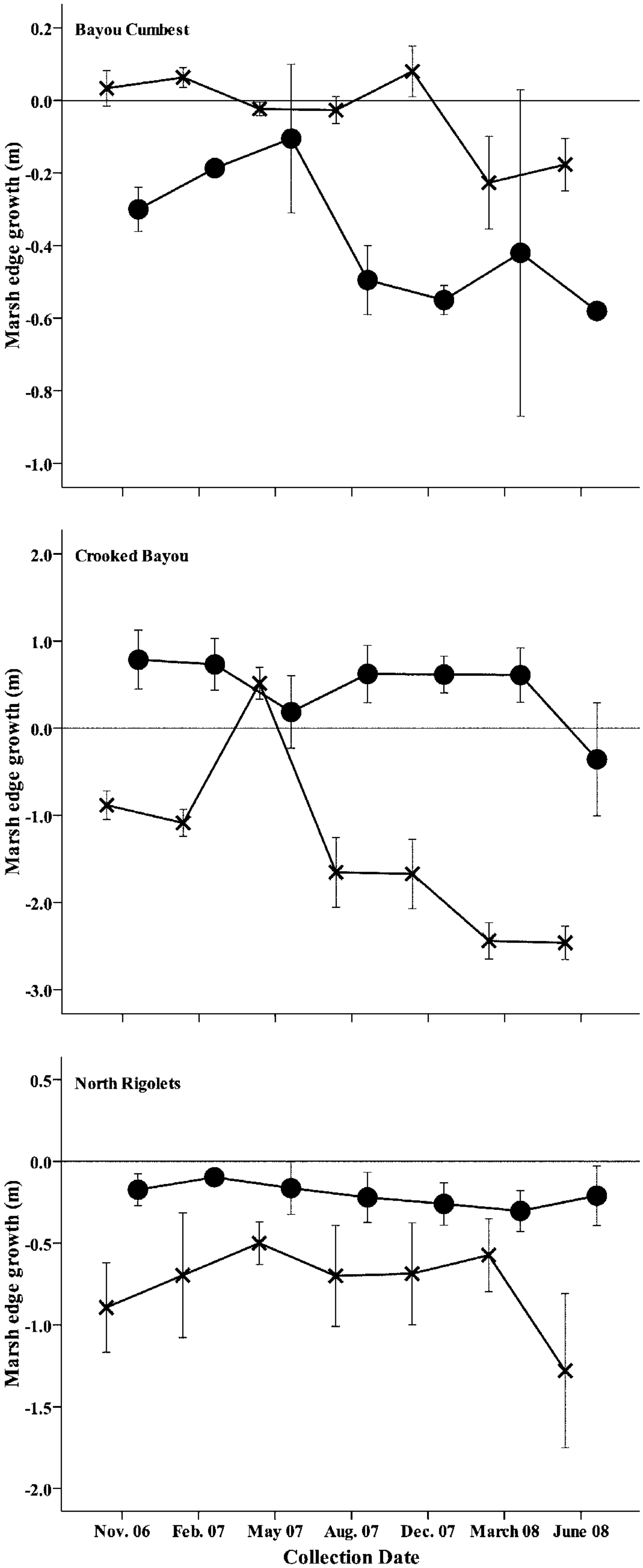

Figure 2. *Plots of change in marsh edge growth (m, $\bar{\chi} \pm 1$ se) since August 2006 by bayou (n = 3) and habitat type (n = 2) over the course of the study. Plotted measurements by habitat are offset laterally from the dates for clarity; actual sampling was conducted over a 1-2 day period during all events. Note the different y-axis scales for the three graphs. For some dates, se was smaller than the size of the symbol used for the mean value. ● - constructed sites; X - natural sites.*

study (Table 1). The lowest temperatures were observed in November 2006 and December 2007 (11.9–14.5°C) and the highest in August 2007 and June 2008 (26.5–29.8°C). Dissolved oxygen varied 3.37–13.60 mg/L in Bayou Cumbest, 2.87–9.70 mg/L in Crooked Bayou and 2.37–10.40 mg/L in North Rigolets. Salinity varied 18.4–29.1 in Crooked Bayou and 18.3–28.8 in North Rigolets, and Bayou Cumbest had the lowest salinity (11.6–29.3).

There was an overall erosion of marsh edge over the course of this study at all sites. Although no differences were noted among bayous (Table 2), marsh edge growth did vary significantly between constructed and natural oyster reefs within all three bayous and over time in Crooked Bayou (Figure 2). This variation was accounted for by significant interaction effects among combinations of bayou, habitat and time (quarter), but each had small F–values and moderate partial η^2 values (Table 2). For example, in Bayou Cumbest marsh edge advanced at the constructed reef through May 2007 and retreated during the remainder of the study. In natural reefs, the marsh edge did not change through December 2007 and then retreated through June 2008 (Figure 2). In contrast, Crooked Bayou marsh edge growth was stable in constructed reefs over time except June 2008 (Figure 2), but natural reefs had positive marsh edge growth between February and May 2007, though overall reductions occurred between November 2006 and June 2008 (Figure 2, Table 2). In North Rigolets, there was slow retreat of marsh edge in the constructed reefs over time while the natural reefs exhibited high variability and an overall retreat over time (Figure 2). Overall, there were significant main effects of habitat, time, and B x H interaction effects, with high F–values and moderate to high partial η^2 values (Table 2), indicating less retreat of the marsh edge in the constructed reefs compared to the natural reefs in all bayous (Table 2). The greatest source of variation was associated with the interaction effect of bayou x habitat (Table 2), with Bayou Cumbest exhibiting more retreat of the marsh edge in constructed versus natural reefs. In contrast, Crooked Bayou and North Rigolets marsh edge retreat was more pronounced in natural relative to constructed reefs (Figure 2). Variability (larger se) in marsh edge growth in natural reef sites was greater than constructed sites in North Rigolets and Crooked Bayou compared to Bayou Cumbest (Figure 2). Mean overall marsh edge retreat was 0.728 m for natural and 0.043 m for constructed oyster reefs.

Discussion

One goal of habitat restoration is to develop a functional habitat where one did not previously exist, or to rehabilitate a degraded habitat (Simenstad et al. 2006) such that system productivity and ecosystem services are enhanced. We determined that constructed oyster reefs slowed the rate of erosion more than nearby natural reefs in the Grand Bay NERR; mean marsh edge retreat was 0.035 m/mo (0.728

m overall) for natural and 0.002 m/mo (0.043 m overall) for constructed oyster reefs. This pattern varied by bayou, however, with the least overall marsh edge retreat at Bayou Cumbest, followed by Crooked Bayou and North Rigolets. Though there were temporal differences noted on all reefs among the three bayous, these changes were most visible at the natural reefs in Crooked Bayou and constructed reefs in Bayou Cumbest. Rates of retreat were similar to that found by Piazza et al. (2005) in Louisiana, who reported a mean overall retreat of 0.08 m/mo (1.68 m overall) in added cultch sites and 0.12 m/mo (2.52 m overall) in non-cultched sites. Though there was no overall mean growth in the marsh edge (except Bayou Cumbest natural sites), the reduced retreat in marsh edge adjacent to constructed oyster reefs highlights the ability of these reefs (representing only 30–35% coverage) to reduce shoreline erosion under the environmental conditions at our sites. It is possible that greater oyster shell coverage on these small intertidal reefs may further retard erosion or enhance sediment accretion and thus growth of the marsh edge.

We had three concerns about our marsh edge growth measurements. First, the PVC posts used for marking the upland to lowland transect may have been subject to movement due to weather and wave action because some stakes during the course of the study appeared to be leaning a bit out of the vertical. To minimize inter-observer variability, we had the same individuals make each set of measurements. Second, short-term studies such as this one may not encompass the full spectrum of conditions, which may have revealed sustained advances or retreats in marsh edge at constructed reefs over a longer time period. A North Carolina study of similar duration (Meyer et al. 1997; 20 mo) found little difference between cultched and non-cultched reefs. However, Meyer et al. (1997) reported a mean advance of 0.26 m over 20 mo, with growth varying by reef location (orientation to wind and wave action); a greater percent cover of oyster shell was also used compared to the Grand Bay NERR sites. Clearly, longer study duration would allow for more accumulation or erosion of sediments along the marsh edge; however, the construction of reefs with oyster cultch within Grand Bay NERR appears to provide some protection of salt marsh shorelines, as has been found in Louisiana (Piazza et al. 2005). Finally, differences existed in sediment composition between sites that may have influenced sediment accretion patterns and erosion. Bayou Cumbest sites had more consolidated clay/sandy sediments whereas at the other two locations, sediments were unconsolidated and muddy. North Rigolets and Crooked Bayou exhibited more erosion than elsewhere, most likely from orientation to the constant southeast wind direction and the fact that Bayou Cumbest had a bit more protection from upland trees than the other two locations. This is consistent with findings by Piazza et al (2005), who proposed that intertidal reefs work better to stabilize marsh edge in low energy than high energy sites.

As ecosystem engineers (Jones et al. 1994, Micheli and Peterson 1999), oysters and the reefs they create provide habitat and stabilize shorelines by buffering wave energy and mitigating erosion caused by boat traffic, storms, and predominant wind direction. Furthermore, by increasing rates of sedimentation they can enhance the growth of emergent marsh vegetation thereby further stabilizing unconsolidated sediments (Coen et al. 1999, Mann 2000, Piazza et al. 2005). By the end of the study, the ecological function of the constructed reefs, as measured by reduction in marsh edge erosion, was equivalent or exceeded the function of nearby natural oyster reefs. The use of small, intertidal reefs to reduce marsh retreat may be a useful management tool to mitigate retrograding deltaic estuarine ecosystems like the Grand Bay NERR.

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