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A hybrid shoreline stabilization technique: Impact of modified intertidal reefs on marsh expansion and nekton habitat in the northern Gulf of Mexico

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ABSTRACT

To mitigate shoreline erosion numerous armoring techniques have been employed extensively along the degrading shores of the Gulf of Mexico (GoM). Shoreline armoring strategies incorporating built vertical structures have resulted in numerous undesired ecological consequences. Bioengineering *hybrid* techniques consisting of "living shorelines" are emerging as an alternative option to mitigating shoreline loss and overcoming ecological shortcomings of hardened structures. Hitherto, only a few studies have assessed efficacy of hybrid techniques on shoreline stabilization and adjacent habitat enhancement. In this study, we integrated permeable intertidal reef-breakwaters (also known as wave attenuation units or WAUs) and predominantly restored native *Spartina alterniflora* marsh vegetation to mitigate erosion along severely degrading shores of a narrow peninsula in the northern GoM. Particularly, we evaluated impacts of a large-scale WAU reef deployment on a range of physical and biological parameters including erosion mitigation (shoreline stabilization), facilitation of created marsh expansion and habitat provision to marsh-utilizing nekton. We compared WAU reefs to adjacent gap areas without WAUs to evaluate the effects of tidal openings on the metrics measured. Our results of over 3 years suggest that, intertidal WAU reefs facilitate in created marsh expansion and the tidal openings between the reef complexes allow free movement of marsh-utilizing nekton fauna. Based on our results, we conclude that hybrid restoration technique is highly efficacious on erosion mitigation, adjacent marsh expansion and habitat creation. However, more works in other coastal systems are required to confirm the impacts of hybrid techniques on erosion mitigation and consequently on marshes and marsh-utilizing nekton.

1. Introduction

One of the major concerns of coastal systems is shoreline degradation. Eroding shorelines devalue the quality of ecosystem services provided by the *ecotones* between land and sea (Fagherazzi et al., 2013). Several attempts have been made to mitigate shoreline erosion by incorporating hardened built structure (e.g., bulkheads, groins, riprap or granite revetment), especially, along the personal waterfront properties in the Gulf of Mexico (GoM) coasts (Douglass and Pickel, 1999; Scyphers et al., 2011). Although hardened built structures aid in erosion mitigation for a certain period, associated undesirable consequences may eventually overwhelm the short-term benefits (Douglass and Pickel, 1999; Gittman et al., 2014). Loss of intertidal habitat and ecosystem services, interference with the movement of organisms, intensification of reflected waves, and undercutting are few undesirable consequences associated with built infrastructures (Board, 2007). Finding a common solution to mitigating shoreline erosion, preserving vital marsh habitats and minimizing interference on nekton movement is a major contemporary restoration challenge (Callaway, 2005; Bilkovic and Mitchell, 2013). Furthermore, protecting coastal habitats and human waterfront properties from relative sea level rise and occasional storm surges demands a "panacea" solution that can effectively address all existing and potential problems (Spalding et al., 2014).

Ecologically sound "living shoreline" approaches are emerging as an alternative to *built* infrastructure and have been advocated along the Atlantic and the Gulf coast states of the USA to mitigate

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nearshore habitat loss and ensure effective deliverance of ecosystem services from the tidal marsh habitats (Board, 2007). The living shoreline approach discourages hard infrastructure deployment for shoreline stabilization; however, built structures could be used to bolster biogenic components (Sutton-Grier et al., 2015). The living shoreline approach incorporates restoration of locally available materials to protect, restore and create habitats by maintaining natural coastal processes. Numerous studies have highlighted ecological benefits from biogenic habitat restoration, e.g., salt marshes (Bilkovic and Mitchell, 2013), oyster reefs (Dillon et al., 2015) and other nearshore habitats (Lewis, 2005; Wilkie, 2012).

Along the Atlantic and the Gulf coasts of the USA, previous studies on living shorelines have mainly focused on oyster reef and saltmarsh restorations. Past studies have assessed the ability of created oyster reefs on abating shoreline erosion (Scyphers et al., 2011), habitat utilization by finfish, shellfish and crustaceans (Dillon et al., 2015) and water quality enhancement (La Peyre et al., 2014). Similarly, studies on marsh restoration have compared the functional ability of restored marshes to natural marshes on nutrient recycling (Sparks et al., 2014), habitat provisioning quality (Sparks et al., 2013) and marsh-dependent infaunal assemblages (Tong et al., 2013). Some studies have further assessed the cost-benefit analysis of restoration (Kroeger, 2012; Sparks et al., 2013). However, studies on hybrid restoration approach comprising of created vegetation and built infrastructure on shoreline protection are rare (see Sutton-Grier et al., 2015).

Approximately, 70% of GoM shorelines are extremely vulnerable to even the weak storms (Stockdon et al., 2012) which may jeopardize the current extent and quality of ecosystem services of the Gulf marshes. Inability of degraded marshes to provide similar ecosystem services as the healthy marshes and the uncertainty involved in the degree of undesirable consequences likely to arise due to marsh degradation are two coupled problems which need immediate attention (Gedan et al., 2009; Morgan et al., 2009). In this aspect, the state of Alabama promotes the living shoreline approaches to manage the degrading shores in their region of the Gulf. However, the use of bulkheads and revetment ripraps in Alabama has constantly been increasing, especially in highly urbanized areas e.g., Mobile Bay (Douglass and Pickel, 1999; Scyphers et al., 2011). The problem of shoreline degradation and loss of marsh and oyster habitats and consequent devaluation of ecosystem services in the GoM could be resolved by incorporating a hybrid bioengineering technique.

In this study, we report a unique restoration endeavor in which modified wave attenuation units or WAU reefs were deployed in the shallow waters of historically degraded shores of a narrow peninsula, then followed by sediment refilling and native marsh restoration. WAUs are modified breakwaters that are laboratory proven to attenuate erosive wave energy by as much as 70% of the incident waves without compromising with the natural ingress and egress of marsh utilizing fauna (Douglass et al., 2012). On the landward side, WAU reefs may aid in expansion of restored vegetation. Once established in new conditions roots and rhizomes of the restored marshes adapt well with the refilled sediment, thus allowing for a self-sustaining restored system where WAU reefs could dampen wave energy to facilitate marsh growth and stabilize the sediment. For restoration purpose, native vegetation (mostly comprising of *S. alterniflora*) was chosen in this study because *S. alterniflora* normally thrives in the seawardmost edge of the GoM marshes. Further, *S. alterniflora* – the most dominant fringing marsh species in the coastal GoM – provides an array of ecosystem services including provision of nursery grounds to commercially and ecologically important finfish species (Beck et al., 2001; Minello et al., 2003). Our objectives in this study were to: (1) determine the efficacy of a large-scale hybrid technique consisting of intertidal reef structures and created emergent marsh vegetation on shoreline stabilization, protection and restoration of ecosystem services of marsh habitats in the shallow waters of northern GoM; and (2) evaluate the effects of tidal openings between the reefs on different physical and biological metrics. Particularly, we evaluated the role of laboratory tested WAU reefs on shoreline erosion mitigation in *real* conditions, and protection and assistance in expansion of created *S. alterniflora* marsh and its habitat provisioning quality to marsh-utilizing nekton.

2. Materials and methods

2.1. Study site

Our study site was located along severely degraded shores of a peninsular structure locally known as Little Bay (LB) in the Portersville Bay of northern GoM (site center: 30.383056, −88.281389; Fig. S1 in the Supporting Information). Stretched from east to west, LB measures 1.6 km of shoreline. This site is characterized by large wind fetch (>5 km). Severe erosion of the site is attributable to wind-generated waves where wind averages about 18 km h^{-1} although Isle-aux-Herbes Island diminishes some wind generated southeast of LB. Tides are diurnal with a range less than 0.5 m. The total peninsular area is about 0.15 km^2 (37 ac). Historical records indicate that LB has suffered erosion for more than 50 years (Fig. S2); further, Hurricane Katrina substantially damaged the already degraded oyster and seagrass beds by interfering with natural sediment movement. Thus, more than 3 km^2 of marsh expanse northward of the breached peninsula remained in imminent jeopardy. To protect the remaining oyster population, seagrass beds and marsh vegetation northward of the peninsula, it was imperative to reconstruct the dissected peninsula, reverse the changes on biogenic resources brought about by Hurricane Katrina, and restore all natural processes to historical conditions.

In neighboring shallow waters, seagrass species comprising shoalgrass (*Halodule wrightii*) and widgeongrass (*Ruppia maritima*) are found. Remnants of the eastern oyster (*Crassostrea virginica*) are also scattered in adjacent intertidal and near subtidal zones indicating the historical presence of the eastern oyster in the vicinity. Fringes of neighboring natural marshes consist of tall form smooth cordgrass (*S. alterniflora*) followed by short form *S. alterniflora*. Higher marshes are composed of *Distichlis spicata*, *Borrichia frutescens*, *Batis maritima* and *S. patens* (Moody et al., 2013a). A boat channel penetrates into Bayou-La-Batre immediately east of the peninsula (Fig. S2). Boat traffic occasionally results in artificially generated wakes, which intensify shoreline erosion when coupled with natural waves.

2.2. WAU reef deployment and dimensions

WAU reef deployment took place between Jan and Apr 2010. WAU reefs were constructed off-site, and later transported and deployed by a barge. Each unit consisted of four-sided, apex-truncated, hollow WAU frustum measuring 2 m height, 3 m × 3 m area at the bottom and 1.5 m × 1.5 m at the top (Fig. S3). All four sides had circular holes (five holes on the south face and two holes on the other faces). Calculations based on erosion history, wave tolerance ability of *S. alterniflora* in the area and wave-hindcast models for shallow waters in the northern GoM indicated that 50–67% of the incident waves at LB should be attenuated for the created marsh to expand naturally (Roland and Douglass, 2005); hence, the wave attenuating units were custom designed accordingly.

Each wave attenuation unit weighed approximately 7250 kg. A total of 546 WAUs grouped in 16 complexes were deployed at LB. Within a complex, reef units were arranged in a saw tooth pattern i.e. two rows of closely placed WAUs. Each WAU complex consisted