The Potential for Created Oyster Shell Reefs as a Sustainable Shoreline Protection Strategy in Louisiana

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Abstract

Coastal protection remains a global priority. Protection and maintenance of shoreline integrity is often a goal of many coastal protection programs. Typically, shorelines are protected by armoring them with hard, non-native, and nonsustainable materials such as limestone. This study investigated the potential shoreline protection role of created, three-dimensional Eastern oyster (*Crassostrea virginica*) shell reefs fringing eroding marsh shorelines in Louisiana. Experimental reefs (25 × 1.0 × 0.7 m; intertidal) were created in June 2002 at both high and low wave energy shorelines. Six 25-m study sites (three cultched and three control noncultched) were established at each shoreline in June 2002, for a total of 12 sites. Shoreline retreat was reduced in cultched low-energy shorelines as compared to the control low-energy shorelines (analysis of variance; $p < 0.001$) but was not significantly different between cultched and noncultched sites in high-energy environments. Spat set increased from 0.5 ± 0.1 spat/shell in July 2002 to a peak of 9.5 ± 0.4 spat/shell in October 2002. On average, oyster spat grew at a rate of 0.05 mm/day through the duration of the study. Recruitment and growth rates of oyster spat suggested potential reef sustainability over time. Small fringing reefs may be a useful tool in protecting shorelines in low-energy environments. However, their usefulness may be limited in high-energy environments.

Key words: ***Crassostrea virginica*, fish, Louisiana, oyster reefs, restoration, shoreline protection.**

Introduction

With global warming and rising sea levels, coastal protection remains a global priority. In many coastal areas, management objectives generally include maintenance of shoreline integrity and reduction of shoreline erosion (Yohe & Neumann 1997; Mimura & Nunn 1998; Klein et al. 2001). A common tool used to combat shoreline erosion involves armoring the land/water interface. Typically, this is done with materials such as limestone rock, metal sheet pile, and concrete mats (Hillyer et al. 1997). The soft sediment composition of many deltaic estuaries is such that heavy and dense materials often sink over time, requiring additional effort and funds for maintenance of breakwater structures (Zabawa et al. 1981; Brodtmann 1991). In areas not prone to strong storm or human-created wave energies (i.e., boat wakes), the planting of native marsh vegetation along shorelines has been used effectively for shoreline stabilization (Gleason et al. 1979). Vegetative plantings, however, also pose challenges to restoration or protection success because high erosive forces may overcome possible shoreline stabilization properties of the plantings (Williams 1993). Particularly in areas with soft sediments, such as are often found along the edges of many salt marshes, alternative approaches are needed.

The Eastern oyster (*Crassostrea virginica*; hereafter oyster) has been called an "ecosystem engineer" (Jones et al. 1994; Micheli & Peterson 1999) because its reefs provide many benefits to coastal and estuarine systems, including provision of habitat, water quality maintenance, and shoreline stabilization (e.g., Bahr & Lanier 1981; Newell 1988; Jones et al. 1994; Breitburg 1999; Coen et al. 1999*a*; Dame 1999; Mann 2000). In particular, oyster reefs are hypothesized to contribute to shoreline stabilization by providing coarse material to reduce wave and other erosive energies along eroding marsh and estuarine shorelines. Oyster reefs also may contribute to shoreline stabilization by producing a crystallizing cement of calcium carbonate (Harper 1997), which allows them to bond together and expand their reefs spatially in three-dimensional space. One study conducted in North Carolina intertidal marshes found that small fringes of oyster cultch resulted in lower marsh edge retreat at one of three sites tested and less retreat following a winter storm at a second site (Meyer et al. 1997).

In coastal Louisiana, protection of shorelines and existing marshes is a top priority (Louisiana Coastal Restoration and Conservation Task Force and the Wetlands Conservation and Restoration Authority 1998). Natural delta subsidence and sea level rise coupled with anthropogenic alteration of hydrologic flow regimes, severance of

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river flooding, and canal dredging have combined to create loss rates in Louisiana over 64 km^2/yr (Britsch & Dunbar 1993; Turner 1997; Barras et al. 2003). As coastal wetlands convert to open water, wetland shorelines become especially susceptible to erosion due to continuous erosive wind and wave forces. This fact has caused Louisiana's coastal restoration program to identify shoreline erosion as a significant coastal loss threat and focus on shoreline protection as one of its three major coastal restoration techniques (Louisiana Coastal Restoration and Conservation Task Force and the Wetlands Conservation and Restoration Authority 1998).

Along with its extensive marshes, Louisiana also contains an extensive oyster fishery, evidenced by the $30 million industry in 2002 supported by oyster beds (NOAA Fisheries, Annual Commercial Landings by Group 1950–2003). Although still a highly productive and viable industry, many of the fringing three-dimensional reefs historically found in Louisiana are gone due to increased saltwater and its accompanying predators and pathogens. To find optimum salinity conditions for oyster production, the fishery has moved steadily inland into areas that are subsiding and eroding rapidly. Cultivated oyster reefs now typical in Louisiana are two-dimensional cultched beds that are consistently reworked by a cycle of resource planting and harvesting. Restoration of three-dimensional living reef structures, in addition to benefiting the estuarine landscape, may provide critical shoreline habitat protection.

We examined the potential for created oyster shell reefs to be used as a natural shoreline protection tool in the soft sediments of coastal Louisiana by determining if small, created shell reefs protected adjacent shorelines. Specific to our study site, we also determined if the experimental reefs were potentially sustainable over the long-term.

Study Area

The study was conducted in Sister (Caillou) Lake in the Terrebonne basin, Terrebonne Parish, Louisiana. This area was selected as being a typical brackish marsh system along the Louisiana coast. Terrebonne basin is an area of high wetland loss (>2,500 ha/yr, Barras et al. 2003), mostly attributed to high (0.6–1.1 meters per century) subsidence rates (Gagliano 1998). Sister Lake is primarily an open water system, fringed by brackish marsh. Water depths in the lake range from 1 to 3 m. Freshwater inputs into Sister Lake are from precipitation run-off and drainage of fresher marshes to the north. Marine inputs result from lunar and wind tides. Dominant winds are typically from the southeast, except in the winter when northerly winds accompany cold fronts. Fetch distance is quite large, and wind-induced erosion is the dominant mechanism of shoreline loss in the lake. Tides range from -0.8 to 1.1 m National Geodetic Vertical Datum (NGVD; 0.3 ± 0.03 m NGVD, $\overline{X}$ ± SE). Marsh level in the area is 0.5 ± 0.1 (SE) m NGVD, and wind-induced flooding of the marsh surface occurs on an average 50% of days per year. Flooding frequency is highest in the summer months (June–September) and lowest during the winter months (December–February).

Mean (±SE) water temperature between 1985 and 2003 was 22.5 ± 0.1°C (range of 0.9–34.9°C; LDWF/USGS 07381349—Caillou Lake southwest of Dulac, LA, U.S.A.). Mean annual salinity between 1985 and 2003 in Sister Lake was 10.9 ± 0.1 ppt (range of 0.1–31.0 ppt; LDWF/USGS 07381349—Caillou Lake southwest of Dulac, LA, U.S.A.). This salinity is conducive to oyster recruitment and oyster spat growth and survival (Chatry et al. 1983; Perret & Chatry 1988). Sister Lake has served as one of the state public oyster seed reservations since 1940 and is managed by the Louisiana Department of Wildlife and Fisheries (LDWF).

Methods

Shoreline Selection

In April 2002, two 450-m study shorelines were selected in Sister Lake. Based on the direction of prevailing winds, one shoreline was located in a high wave energy environment and the other was located in a low wave energy environment. Each shoreline was located on a Digital Orthophoto Quarter Quadrangle image, divided into six equal (75 m) shoreline sections and numbered. One 25-m site was randomly located within each 75-m shoreline section and randomly assigned for reef placement (cultched) or no reef placement (noncultched). Adjacent sites were not selected. Six 25-m study sites (three cultched and three noncultched) were established at each shoreline, for a total of 12 sites. Each study site (cultched and noncultched) was delineated with 5 cm $\times$ 6–m PVC poles anchored in the sediment along the shoreline.

Experimental Reef Deployment

Experimental oyster shell reefs were deployed in June 2002. A total of 17.5 m^3 of shucked oyster shell (cultch material) was off-loaded at each cultched site, and an experimental reef (25 $\times$ 1.0 $\times$ 0.7 m) was constructed similar to Meyer et al. (1997). Reefs were built as close to the shoreline as possible. All reefs were placed within 5 m of the shoreline and were intertidal (Fig. 1). In-depth monitoring of the marsh, shorelines, and oyster shell reefs occurred monthly from June 2002 through June 2003.

Marsh Characterization

Water quality (salinity, temperature, dissolved oxygen), vegetation, and soils data were collected monthly to characterize the study site and detect any changes that may occur during the project period. Triplicate plots were established at each site within 5 m of the water–marsh interface for monthly measurement of percent vegetative cover and oxidation-reduction (redox) potential. Percent vegetative cover (by species) was assessed inside a 1-m^2 PVC quadrat (Pahl et al. 1997). Redox potential was measured monthly using a standard calomel electrode (Patrick et al. 1996).

Figure 1. Cultched shoreline created at Sister Lake, Louisiana, showing intertidal oyster reef ($25 \times 1.0 \times 0.7$ m). Each reef was created with 17.5 m^3 of shucked oyster shell.

Triplicate measurements were taken at each of the vegetation plots used for percent vegetative cover.

Quarterly evaluation (September 2002, December 2002, March 2003, June 2003) of aboveground vegetative biomass, belowground biomass, soil organic matter, and soil bulk density was conducted at randomly placed triplicate plots. To measure aboveground biomass, three randomly placed, 0.25-m^2 quadrats were cleared of all vegetation at the soil surface. Vegetation was returned to the lab where it was separated by species into live and dead stems, dried at 60°C for 48 hours, and weighed (0.001 g; Kuhn et al. 1999). Triplicate, random, 4×15–cm cores were collected for measurement of belowground biomass, soil organic matter, and soil bulk density. Belowground biomass was determined by sieving cores of mineral matter. Material remaining was dried at 60°C for 48 hours and then weighed (0.001 g). Percent soil organic matter was determined by loss on ignition in a muffle furnace (Cahoon & Turner 1989). Soil bulk density cores were divided into three 5-cm sections. Sections were dried at 60°C for 48 hours and then weighed (0.001 g). Bulk density was calculated as gram per cubic centimeter.

A survey of marsh elevation was conducted once in January 2003 at each shoreline with a survey transit and staff. Water quality data were obtained from a U.S. Geological Survey real-time data collection platform located between study shorelines (LDWF/USGS 07381349—Caillou Lake southwest of Dulac, LA, U.S.A.). Hourly data (June 2002–June 2003) were downloaded to calculate salinity, water temperature, stage, and flooding frequency and duration during the research project.

Shoreline Change

Shoreline advance or retreat was measured at each site using techniques similar to Meyer et al. (1997). Specifically, triplicate transects were established within each site with permanent base stakes (2×3–cm PVC) located in the marsh and in the water. A shoreline marker stake was placed at the shoreline edge. A tape measure was stretched level between base stakes and read at the shoreline marker. Baseline measurements of shoreline position were made at each site immediately after placement of the shell reefs, and transects were visited monthly, at which time shoreline markers were replaced. To ensure consistent measurements throughout the study, monthly shoreline position was measured by the same investigator. Shoreline edge was defined as the farthest waterward extent of the wetland macrophytes. Mean shoreline retreat rates were calculated at each site based on the triplicate measures and standardized to 28-day rates for analysis and interpretation.

Reef Sustainability

Triplicate, randomly selected, 0.06-m^2 shell samples were removed from each reef monthly. Oyster spat ($\leq$30 mm) on each shell were counted, measured, and categorized as live/dead (Supan 1983; Chatry et al. 1983). Mean number, size, and proportion of live versus dead oyster spat per shell were recorded monthly.

Statistical Analyses

Data were tested for normality with the Shapiro–Wilks test. When necessary, data were logarithmically transformed to achieve normality. Means of subsamples (triplicate measurements) were calculated for each sampling date per site and used for analysis. Analysis of variance (ANOVA; SAS, PROC GLM) was used to test, separately, for statistical differences in shoreline retreat, soil, and vegetation data between treatments (cultched vs.

noncultched) and wave energies (high and low). Comparison of least-square means was used, post-ANOVA, to detect significant differences ($p < 0.05$). Data are reported as mean ± SE unless indicated differently.

Results

Study Site Characteristics

Environmental characteristics during our study were typical of long-term (18 years) means. Mean (±SE) salinity was 9.4 ± 0.0 ppt (range of 0.1–24.0 ppt). Mean water temperature was 23.2 ± 0.1°C (range of 5.6–34.2°C). Tides averaged 0.4 ± 0.2 m NGVD (range of −0.2–1.4 m NGVD). On average, marshes were flooded 8.8 ± 1.1 hour/day. No significant differences were found between sites in temperature, salinity, or dissolved oxygen.

Marsh Site Characteristics

Vegetation percent cover, above- and belowground biomass were similar at all study sites (ANOVA; $p > 0.05$). Marsh areas in Sister Lake were dominated by Smooth cordgrass (38%; *Spartina alterniflora*), Saltgrass (27%; *Distichlis spicata*), and Black needlerush (27%; *Juncus romerianus*). Vegetation species found in lesser abundance included Salt meadow cordgrass (*Spartina patens*), Marsh elder (*Iva frutescens*), Saltmarsh morning-glory (*Ipomoea sagittata*), Saltwort (*Batis maritima*), Virginia glasswort (*Salicornia virginica*), and Black mangrove (*Avicennia germinans*). Aboveground vegetation averaged 76.1 ± 4.8 stems/m^2 and 75.4 ± 3.2 g/m^2. Belowground biomass averaged 6.6 ± 0.3 g/cm^3. Mean bulk density in the marsh soil was 0.44 ± 0.01 g/cm^3, and mean organic content was 21%. Soils were highly reduced ($E_H = -235 \pm 0.08$ mV).

Shoreline Change

For all sites, mean monthly retreat ranged from 0.03 to 0.15 m. Shoreline retreat differed significantly by treatment and energy over the 1-year time period of the study (Table 1). Mean shoreline retreat from June 2002 to June 2003 was significantly lower at cultched sites (ANOVA; $p = 0.007$, 0.08 ± 0.02 m/month) and at low-energy shorelines (ANOVA; $p < 0.001$, 0.06 ± 0.01 m/month) as compared to noncultched (0.12 ± 0.01 m/month) and high-energy shorelines (0.14 ± 0.01 m/month). Significant differences in shoreline retreat were found between cultched and noncultched treatments only for low-energy sites; however, significant differences were found by energy for both cultched and noncultched plots (Table 2). Highest shoreline erosion rates during any time period occurred between October and November following two significant storm events impacting the study site (Table 2).

Table 1. Results of ANOVA for differences in shoreline erosion rates by treatment and energy at Sister Lake, Louisiana, from June 2002 to June 2003 ($N = 12$).

Source	*df*	$\overline{X}$	*F Value*	*p Value*
Energy	1	0.018	42.73	<0.001
Treatment	1	0.005	13.23	0.007
Energy × treatment	1	0.0009	2.11	0.18

Reef Sustainability

A total of 30,527 oyster spat (≤30 mm) were counted on 6,044 sampled shells (4.9 ± 0.1 spat/shell). Recruitment of oysters began immediately upon creation of reefs in June 2002. Oysters began setting within 1 month of shell placement. Spat set averaged 0.5 ± 0.1 spat/shell ($N = 460$) in July 2002 and peaked in October 2002, with an average of 9.5 ± 0.4 spat/shell ($N = 542$; Fig. 2). No significant difference in oyster spat numbers was detected between low- and high-energy sites.

Oyster spat growth was positive throughout the year (Fig. 2). Spat averaged 3.4 ± 0.2 mm after 1 month (July 2002; $N = 579$) and 23.0 ± 0.4 mm ($N = 2{,}252$) after 1 year (June 2003). Maximum monthly mean spat size was observed in May 2003 (28.4 ± 0.3 mm; $N = 1{,}963$). On average, oyster spat grew at a rate of 0.05 mm/day. Smaller mean spat sizes in June and July 2002 corresponded with the spring spat set. No significant difference in oyster spat size was detected between low- and high-energy reefs.

Discussion

Shoreline Retreat

Shoreline retreat was reduced in cultched low-energy environments (Table 2) as compared to noncultched low-energy environments but was not significantly different between cultched and noncultched sites in high-energy environments or following two tropical storm systems (Table 2). These results suggest that small, created fringing reefs may be effective in low-energy environments with retreating shorelines but not in higher energy environments, including storm events. The lack of shoreline protection in the higher energy environment likely indicates that either (1) the small created reefs in this study were inadequate for the higher energy environment or (2) in high-energy environments (i.e., constant prevailing winds across a large, shallow, open fetch), fringing oyster shell reefs alone may not be a viable option to fully protect shorelines.

In a similar study completed in North Carolina, Meyer et al. (1997) found almost no differences between cultched and noncultched study sites over a 1.7-year period when created reefs were placed along created dredge material marshes. Shoreline change in that study resulted in an advance of 0.26 m for both cultched and noncultched treatments. This contrasts with our results, which show a mean overall shoreline retreat of 0.10 ± 0.01 m for both

Table 2. Mean monthly shoreline change (m) standardized into a 28-day rate.

Energy	Treatment	Shoreline Change (m) by Date: June 2002–July 2002	July 2002–August 2002	August 2002–September 2002	September 2002–October 2002	October 2002–November 2002	November 2002–December 2002	December 2002–January 2003	January 2003–February 2003	February 2003–March 2003	March 2003–April 2003	April 2003–May 2003	May 2003–June 2003	June 2003–July 2003
High energy	Cultch	0.04	−0.01	−0.20[b]	−0.16	−0.33	−0.17	−0.04	−0.02	−0.30	−0.15	−0.12	−0.09	−0.13[b]
	Noncultch	0.07[c]	−0.20	−0.45	−0.14	−0.30	−0.07	−0.09	−0.04	−0.11	−0.08	−0.22	−0.18	−0.15[c]
Low energy	Cultch	−0.42	0.17	0.17[b]	−0.09	−0.37	−0.02	0.00	0.03	−0.03	−0.10	0.15	−0.10	−0.03[a,b]
	Noncultch	−0.42[c]	0.07	−0.08	−0.03	−0.37	−0.04	−0.02	0.00	−0.05	−0.11	−0.16	−0.10	−0.09[a,c]

Positive values indicate marsh edge advance, and negative values indicate marsh edge retreat. Dashed borderline represents time period of two landfalling tropical storm system (TS Isidore and Hurricane Lili).
Solid borderline represents time period of highest shoreline change rates.
[a] Significant difference between cultched and noncultched plots ($p < 0.05$).
[b] Significant difference between high- and low-energy sites for cultched plots ($p < 0.05$).
[c] Significant difference between high- and low-energy sites for noncultched plots ($p < 0.05$).

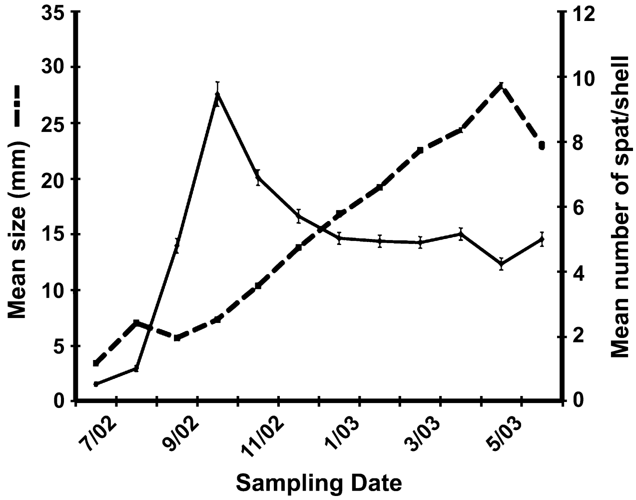

Figure 2. Mean (±SE) number and size of oyster spat per shell sampled monthly from experimental oyster reefs from June 2002 to June 2003 at Sister (Caillou) Lake, Louisiana.

cultched and noncultched treatments (cultch = 0.08 ± 0.02; noncultch = 0.12 ± 0.01), suggesting that these researchers were working in a very different environment compared to the eroding coastal marshes of Louisiana. Meyer et al. (1997) also found lower marsh edge retreat in cultched areas during the period in which a late-winter storm hit one of their sites (Harker's Island) in 1993. This also contrasts with our findings of higher shoreline retreat following two heavy tropical storm events.

Although our experimental reefs proved to be able to withstand strong tides and winds, the reefs did not appear to prove beneficial in protecting the shorelines following two landfalling tropical systems a week apart in 2002 (Table 2). The first system (TS Isidore) came ashore as a strong tropical storm and made landfall at Grand Isle, Louisiana (approximately 90 km east of Sister Lake), on 26 September 2002. Winds in that system exceeded 28 m/second, and the study area was affected by high winds. Sister Lake, located west of the system, was unaffected by the storm surge. Mean water level during the storm was 0.47 m NGVD. The second system (Hurricane Lili) came ashore as a category 2 (Saffir Simpson) hurricane and made landfall at Intracoastal City, Louisiana (approximately 110 km west of Sister Lake), on 3 October 2002. Sister Lake was located in the northeast quadrant of the landfalling hurricane and was affected by hurricane force winds and storm surge. Anemometers and water level gauges failed during the storm; however, maximum sustained winds during landfall exceeded 41 m/second, and storm surge was estimated at 3–4m NGVD at Cocodrie, Louisiana, just east of Sister Lake. Hurricane Lili did substantial damage to coastal infrastructure, docks, and residences in the Sister Lake area. Rapid elevation of wind and water level certainly produced very high wave energies and situations for transgressive movement of reef material. Our experimental reefs did not move or roll over after a direct hit by the storm.

Hurricanes have been responsible for massive shoreline erosion, particularly along barrier islands (Stone et al. 1997). In Louisiana, shoreline retreats of up to 30 m have been shown for the Chandeleur Islands during Hurricane Frederick (category 3) in 1979 (Kahn & Roberts 1982). Similarly, the Isles Dernieres underwent widespread breaching during Hurricane Juan (category 1) in 1985. Rapid water level increase associated with storm surge has been predicted to be the time for the most destruction (Halford 1995). Although our study did not take place on barrier islands, we expected to see some dramatic changes at our sites immediately following the two storms. Shoreline change during the month in which both storms passed over Louisiana was not outside the range of all other months, although (1) shoreline change for all treatments was highest in the month following the storm events (October 2002–November 2002; Table 2) and (2) the pattern was reversed with higher shoreline retreat at cultched sites as compared to noncultched sites during the month in which both storms passed over the study site (September 2002–October 2002; Table 2).

The high shoreline retreat rates following the storms may be due to the shoreline being made more susceptible to erosion or "softened up" by the passage of the extreme event. This phenomenon has been documented for shoreline bluffs in the Neuse River estuary, North Carolina, after passage of hurricanes Bertha and Fran (Phillips 1999).

The higher shoreline retreat at cultched sites during the time in which both storms passed over the area may be due to a combination of scour and water trapping behind the reef and may also explain the lack of significant difference between cultched and noncultched sites in the higher energy environment. During storm events our intertidal reefs were submerged. Submerged reefs cause waves to shoal and break, thereby dissipating part of their energy over the reef crest (Stauble & Tabar 2003). Water passing the ends of the reef structure is only partially slowed, causing a current that wraps around the end of the structure and an effect known as scour. In certain situations, this scour can cause accelerated erosion immediately behind the ends of structures such as seawalls, breakwaters, and reefs (Hughes & Schwichtenberg 1998). In a review of six installations of modular submerged, narrow-crested breakwaters, Stauble and Tabar (2003) found in all instances (1) evidence of scour at the landward edge of the breakwaters and (2) settlement of the breakwaters caused by toe scour and turbulence induced by trapped water interacting with waves. In two of the six cases where single-solid line reefs were employed, this interaction caused scour and erosion of the beach behind the structures. Larger reefs may prove less susceptible to the combined effects of scour and water trapping. Our experimental reefs were so short (25 m) that scour from both ends may have affected the entire length of shoreline behind them. Longer reefs may potentially provide a larger area protected from these effects.

Sustainability

Oysters in the northern Gulf of Mexico generally experience two spawning events (Supan 1983; Banks & Brown 2002); and thus, new individuals are readily available to recruit to existing reefs, contributing quickly to reef maintenance and sustainability. Oyster larvae are gregarious (Crisp 1967; Hidu 1969; Kennedy 1996), and water-borne chemicals from conspecifics are known to stimulate settlement (Hidu et al. 1978). This allows oyster reefs to maintain themselves as new recruits settle and grow. Oyster larvae quickly recruited to the created reefs and showed a general increase in mean size during the course of the experiment, indicating that reef maintenance was not likely to be a problem in this region. Created intertidal reefs in North Carolina, as measured by oyster cluster production, also proved to be self-sustaining because created reefs produced oyster clusters at levels equal or above that of adjacent natural reefs (Meyer & Townsend 2000). Sustainability is an important component to note because maintenance requirements would likely be reduced on created oyster shell reefs as opposed to other heavier shoreline protection structures (i.e., limestone rock breakwaters) that usually necessitate placement of additional material over time to maintain their effectiveness.

Although oyster reefs are often cited as providing valuable forage and shelter habitat for reef-associated fauna (Coen et al. 1999*b*; Glancy et al. 2003; Minello 1999; Posey et al. 1999; Plunket 2003), vegetated shoreline habitat (i.e., marsh edge) has also been shown to provide valuable nekton habitat (e.g., Baltz et al. 1993; Peterson & Turner 1994; Peterson et al. 2003), and a potential concern of artificial reef systems placed near shore is their impact on nekton habitat and use, including shoreline (flooded marsh) accessibility. Placement of our fringing created reefs did not significantly alter nekton shoreline use between clutched and noncultched sites (M. La Peyre, B. Piazza, and P. Banks, unpublished data), which may be due to the small reefs and/or the location of the created reefs (within 5 m of shoreline but not on the shoreline).

Practicality

Whole oyster shell is an ideal material with which to protect shorelines because the shell is native to coastal Louisiana, becomes tightly packed, and is lighter than traditional shoreline protection materials (i.e., limestone rock). The sustainability and continual growth and hardening of created oyster shell reefs should cause them to become more effective over time. Heavier shoreline armoring techniques, such as limestone rock breakwaters, are difficult to support in soft sediments and usually necessitate placement of additional material over time to maintain their effectiveness.

Although not an insurmountable problem, one issue to be resolved in using oyster shell as a shoreline protection tool lies in the difficulty in obtaining enough shell to properly fringe an eroding shoreline. Problems of low oyster shell supply and large spatial dispersion of shell sources may result in higher project costs, possibly making large-scale restoration projects cost prohibitive. This experiment used only 107 m^3 of shell material to construct each of the six experimental reefs, and far more shell material would be required to construct shoreline protection breakwaters for coastal restoration purposes. Although minimal amounts are used by the LDWF for cultch planting activities on the public oyster seed grounds (Dugas 1988), similar to other states (i.e., South Carolina), most shell is used in roadbed and parking lot construction poultry feed additive, or as discarded in landfills, or sold to out-of-state purchasers of oysters. In South Carolina, an experimental shell recycling program (South Carolina Oyster Restoration and Enhancement Program, 2005) is being used to return more shell to the coastal waters. Although a similar program is being investigated for Louisiana, no such program yet exists. Although oyster shell reefs may provide a self-sustaining shoreline protection tool for certain environments, the use of oyster shell reefs may not be a practical tool, until the issue of shell availability is resolved.

Conclusions

The establishment of fringing oyster shell reefs in coastal marsh environments is a particularly attractive shoreline stabilization method because it involves (1) the use of native materials; (2) the potential for sustainability and possible growth over long temporal scales; and (3) the added value of contributing to overall ecosystem stability and quality through its habitat creation and water quality functions. Because oyster reefs are common in many estuarine habitats, their use as a shoreline protection tool would be convenient and relatively cheap, if a steady supply of shell exists. Our results demonstrated that in low-energy environments, the creation of small fringing reefs may be useful in slowing shoreline erosion. Furthermore, the reefs were found to have high spat recruitment and growth, suggesting potential sustainability. In coastal Louisiana where oyster reefs are extensive and other hard materials such as limestone are virtually nonexistent in the coastal zone, the use of small, created, fringing oyster shell reefs has the potential to provide a useful shoreline stabilization tool to coastal managers under low-energy environments.

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