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Landscape Management and Native Plantings to

Preserve the Beach

Between Biloxi and Pass Christian, Mississippi

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Landscape Management and Native Plantings to Preserve the Beach Between Biloxi and Pass Christian, Mississippi

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Abstract

Erosion on the 42-kilometer manmade beach between Biloxi and Pass Christian takes three forms. The southeast and southerly winds that prevail for much of the year blow sand over the seawall onto the highway bordering the beach to the north. Storm water from rain washes sand down the beach toward the Mississippi Sound to the south. Wave action and currents remove sand from the beach-water interface during high-energy events. Current beach management practices exacerbate the erosion process and shorten the time interval between renourishment projects. Raking and grooming the beach fluffs the sand, increasing its vulnerability to erosion caused by wind and storm water runoff. Heavy equipment compacts the sand beneath the fluffed layer. The ability of rainwater to infiltrate the compacted sub-sand is reduced, resulting in more water transport down-beach than would otherwise be the case, increasing sand transport with the runoff. Use of native plant species on the beach represents an alternative to current management practices for much of the beach. Native plants are adapted to survive in the harsh conditions that are common in a beach environment. Native plantings will inhibit or halt all three erosion processes, allowing renourishment projects to be delayed or avoided.

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INTRODUCTION

The 42-kilometer beach between Biloxi and Pass Christian, Mississippi, is one of the longest "man-made" beaches in the United States (Schmid, 2003). The beach borders the Mississippi Sound in the northern Gulf of Mexico. It is considered "low energy," meaning that significant sand movement occurs as a result of high-energy events (Schmid, 2001). These events most frequently take the form of storms (hurricanes, tropical storms, and lower order events). Significant sand movement may also accompany extended periods of higher energy waves caused by wind in the absence of precipitation.

Since the first sand-addition project in 1951 (Canis, 1985), the beach has experienced ongoing erosion. The erosion has necessitated additional sand nourishment projects at reduced time intervals. Sand renourishment is deemed necessary due to the critical role of the beach in the protection of the sea wall that separates the beach from the residential and commercial properties located to the north. Sand renourishment is financially, energetically, and environmentally costly.

All 42 kilometers of the beach are currently managed in essentially the same way. The beach is kept clear of encroaching vegetation, groomed, and raked using heavy equipment. It is also graded to maintain a flat beach profile. Sunbathers and other visitors use some sections of the beach intensively. Such uses

Figure 1. Wind erosion on the 42-kilometer beach.

require intensive management and grooming. Much of the beach receives infrequent direct use. These sections do not require the same degree of care and may be amenable to other management approaches. Other management approaches may be preferable if they reduce erosion and more effectively protect the shore.

Soft engineering is becoming more prevalent in the control and mitigation of coastal erosion (Doody, 2002). The goal of soft engineering approaches is to work with natural processes rather than in opposition to them (Fleming, 1996). Use of native plants to implement a soft engineering approach has been shown to be a cost-effective option (Jones and Hanna, 2004).

Vegetated surfaces resist erosion much more effectively than surfaces without protective vegetation (Morgan and Rickson, 1995). Coastal beach environments present harsh conditions for plant survival (Garcia-Mora et al., 1999). As a result, native plant species (i.e., plants adapted to tolerate these conditions) are preferred. Use of native plants is a central tenet of bioengineering as applied to environmental restoration (Perrow and Davy, 2002).

In this bulletin, we will describe demonstration projects that began more than 10 years ago on sections of the beach located in Biloxi, Mississippi. Although this work has focused mainly on developing methods that reduce the need for beach renourishment, recent concerns related to global warming have increased the importance of the work. It has been suggested that the frequency and/or the energy of storm events may increase as a result of warming (Santer et al., 2006). It also appears likely that a sea level rise of 20 centimeters or more will occur in the next 50 to 100 years (Csatho et al., 2008). Either or both of these conditions will have a profound effect on the erosion problem and the difficulty of retaining the sand beach. The integrity of the residential and commercial areas along Mississippi Sound ultimately depends upon the integrity of the beach. In the face of the increasingly erosive events likely to occur in coming years, use of native plants to stabilize the beach is no longer simply a useful option. It may now be a practical necessity. The projects described in this bulletin clearly demonstrate that there is a viable alternative to the conventional management of "low-energy" beaches such as those found on the Mississippi Gulf Coast.

In this bulletin, we will outline some salient characteristics of the beach and its flora. We will then discuss the three forms of erosion in detail, combining measurements made on site with comparable measurements and experiences from similar sites elsewhere. We will then conclude with a discussion of methods to maximize plant survival in the harsh beach environment.

Despite the long duration of this project, it is still very much a work in progress. This study demonstrates how the most basic bioengineering erosion control technique, use of native vegetation, can slow erosion at a low-energy beach and build the beach vertically. The most recent developments — techniques to create small marshes at will along the water edge and to maximize plant survival in the absence of irrigation — are still under way. In this project, there has always been something else to try before the project could be considered complete. As a result, we have delayed preparing a comprehensive report of the project. Having reached the 13th anniversary of its beginning, it is clear that a comprehensive written record is overdue. As a result, this report will conclude with some important questions completely answered and with others only partly resolved.

NATURAL AND CULTURAL HISTORY OF THE 42-KILOMETER BEACH

Strictly speaking, it may be a misnomer to refer to the 42-kilometer beach between Pass Christian and Biloxi as "man made." Most pictures from the 19th and early 20th centuries show a thin strip of beach along the water's edge (Figure 2). The town of Long Beach was named for "the long sloping beaches of white sand that lay along its shoreline" (Hearn, 2004). According to Kathleen Bergeron, long-time columnist for the Biloxi Sun Herald,

> *… it points out such a misconception that people have about our beach. We have always had a sand beach; it was a natural sand beach unlike today, which is well groomed. Because if you go back to what it was like in the early days, and even if you read Iberville's journals on up into time, you will see that it was a beach that had a lot of freshwater inlets that dumped out from it; it had a lot of grasses; the oak trees and the cypress trees grew right down to the water line.* (Center for Oral History and Cultural Heritage, 1999)

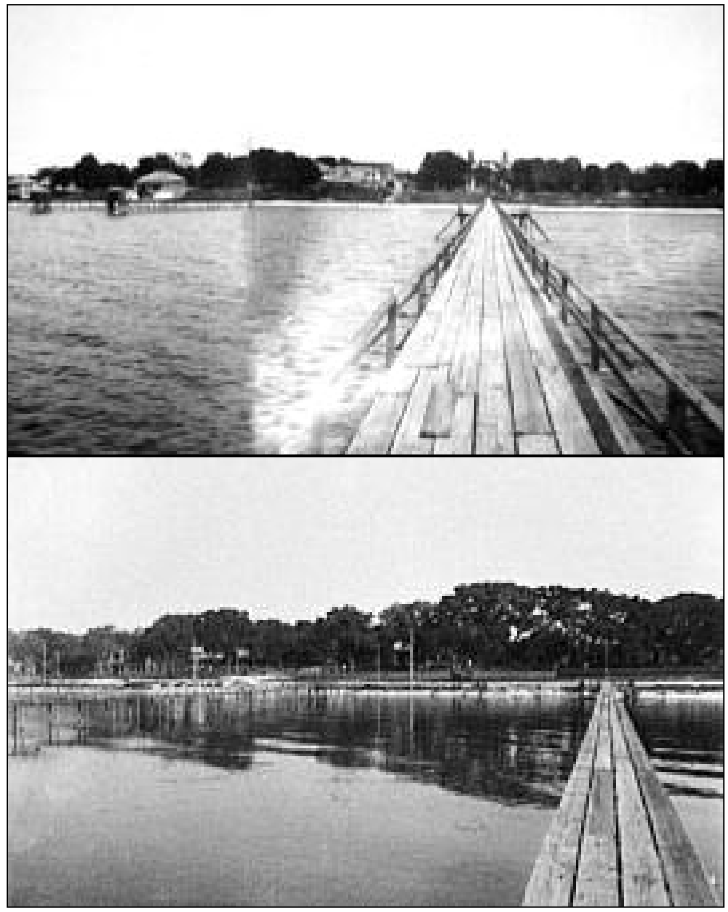

Figure 2. Pass Christian (top) and Biloxi (bottom), both 1901 (Courtesy Library of Congress).

From this passage, one can infer that the water's edge was largely a sandy strip, with intermittent salt marsh plants and some terrestrial plants. Given the history of erosion that led to the sea wall, storms may have periodically stripped the sand and vegetation, revealing the clay beneath the surface.

A series of six hurricanes in a 23-year period (1893-1916) caused so much property damage that popular opinion favored some sort of storm protection structure. The result was the poured-in-place concrete sea wall that was constructed 1923-1927 (Figure 3). The efficacy of the seawall was not tested for nearly 20 years after its dedication because of the lack of powerful hurricanes during this period. Pictures from the first 20 years appear to indicate that an intermittent beach in front of the seawall may have been present (Figure 4). It is probable that wave reflection at the seawall led to scour that limited sand accumulation below the seawall (El-Bisy, 2007). The presence of the seawall, and the apparent protection it afforded, allowed local officials to construct a major roadway that bordered the water edge. This roadway, which supplanted Pass Road as the major east-west route, was eventually expanded to four lanes and became U.S. Route 90.

In 1947, a serious hurricane not only stripped the seawall of whatever sand that had accumulated there, but damaged the seawall and the new highway in a number of locations (Hearn, 2004). Undermining of hard armor seaside structures is a well-known phenomenon (French, 2001). It was decided that renourishment of the beach with dredged sand would prevent undermining. The sand beach was created in 1950-52. Since that time, there have been five renourishment projects to replace sand that has been eroded away.

Beach renourishment in general, and the pattern of the renourishments on the Mississippi coast in particular, are troubling. Beach renourishment projects are energetically costly. Using conventional beach renourishment techniques, it requires, on average, 0.25 liters of diesel fuel to transport 1 cubic meter of sand to the beach.[1] For the 2001 renourishment project, this was equivalent to 210,000 liters of petrochemical fuel and resulted in release of 550 metric tons of the greenhouse gas carbon dioxide, in addition to other types of pollutants (EPA, 2005). Beach renourishment is environmentally damaging. The sand is mined from the local seabed and typically damages the local ecology of the mining site (Speybroeck et al., 2006). Finding sand suitable for use in renourishment projects is a problem in the Mississippi Sound due to the scarcity of predominately sand sediment (Schmid, 2001). This problem is especially alarming due to the general trend of decreased time intervals between beach renourishment projects (Table 1).

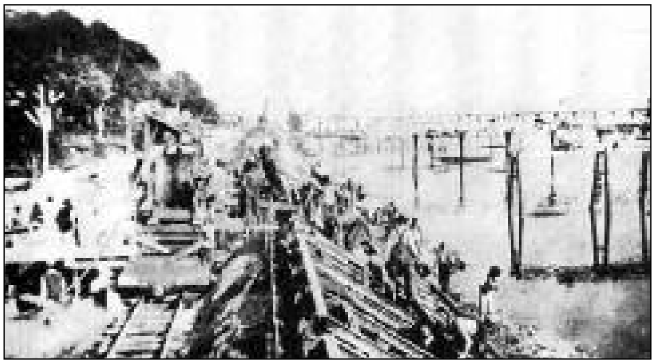

Figure 3. Construction of the stepped seawall, 1924 (Sullivan, 1985).

Table 1. Sand Nourishment on the 42-km Beach.

Year	Volume of sand (M m^3)
1950-51	4.5
1973	1.45
1985	0.76
2001	0.84
2008	0.89

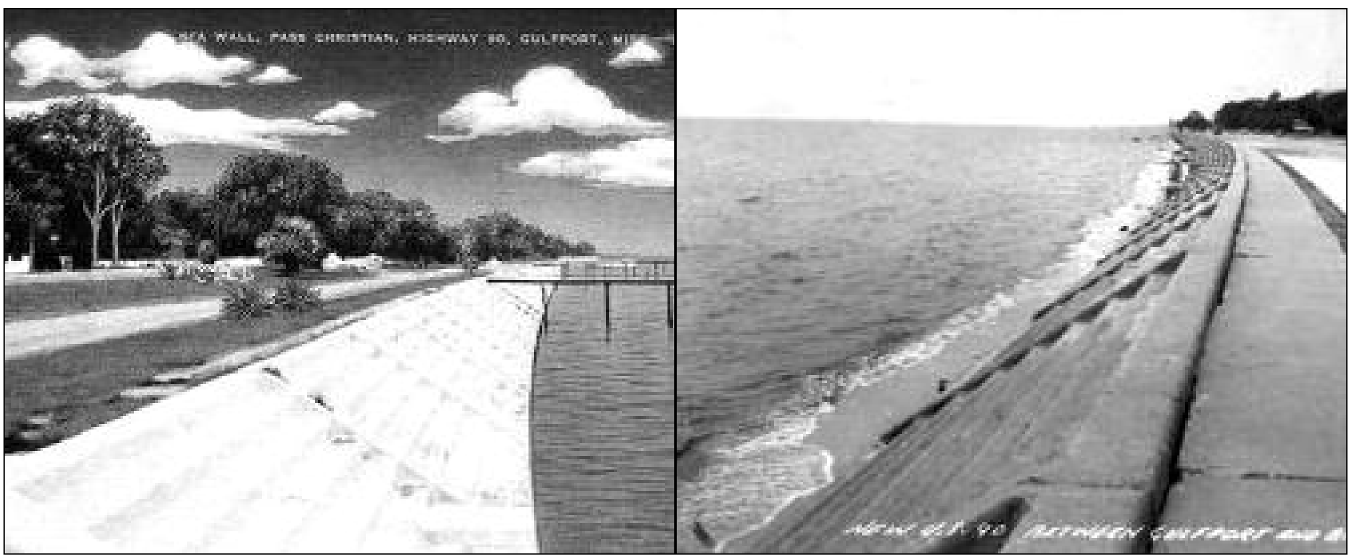

Figure 4. Pictures of the seawall on the Mississippi coast before the 1951 beach nourishment project.

[1]Assumptions: 420 horsepower (hp) pump; 0.04 gallons of diesel fuel / rated hp * hour; rating factor = 0.50; 1,500 cubic yards per 8-hour day = 67.2 gallons of fuel per 1,500 cubic yards. Converted to SI = 0.23 liters per cubic meter. Add 0.02 liters for heavy equipment to distribute sand on beach, move pipes, etc. (Schexnayder et al., 2003; Bellantoni et al., 2004).

The Beach as a Stabilizing Coastal Element

In the 19th century, loss of sections of coastal property due to erosion was a concern for the landowners but had relatively little impact on the local and regional economy. In the 20th and 21st centuries, with the investment of public moneys in an adjacent highway and the growth of the commercial and gaming enterprises on the waterfront, protecting the integrity of the coastal edge has become much more significant (Figure 5).

If the current seawall will continue to be used to armor the mainland property, then maintenance of the beach for protection of the seawall is essential. Given the expense, difficulty, and damage associated with renourishment projects, it is to everyone's advantage to minimize the frequency that such projects will be necessary. One way to do this is through the planting and proper maintenance of vegetation that is adapted to the rigor and vicissitudes of the beach environment. As mentioned previously and described in detail in following text, native beach grasses, plants, shrubs, and trees can survive in this environment and will inhibit erosion due to wind, storm water runoff, and wave energy.

This fact is especially important at present because the potential for erosion appears likely to increase in the near future. Recall that the principal source of sand movement in a low-energy beach environment is storms and other high-energy events. Recall also that the 56-year history of beach sand transport has been sand loss, rather than balanced sand loss and gain. It is reasonable to suppose that any increase in the frequency or magnitude of high-energy events will only exacerbate the erosion problem that exists at present.

The occurrence of more or higher energy events has been predicted as a logical outcome of global warming. This prediction is based on the assumption that increased thermal energy in the atmosphere will result in an increase in the kinetic energy of atmospheric events. The premise that global warming will result in more storms has been challenged in some quarters. Based on model predictions, Knutson et al. (2008) suggested that fewer, rather than more, storms will occur as a result of warming. These authors also predicted that storms that do occur would be more powerful than storms at present, so the threat of increased sand loss due to high-energy events remains very real under this more favorable scenario. Knutson et al.'s view remains a minority opinion. Scientific consensus appears to strongly favor both increased number and intensity of storms (Karl et al. 2008).

Another threat to the beach is sea level rise. There is nearly universal agreement among scientists that warming will result in an increase in the elevation of the world's seas (e.g., Karl et al., 2008).

Figure 5. Left: View of the Biloxi Lighthouse from the east, beginning of the 20th century. Right: Same view, 2006 (the lighthouse is just beyond Rt. 110).

Bruun's erosion rule (Bruun, 1962) has been used for decades to estimate the effect of sea level rise on the equilibrium slope of the coastal sea floor. Bruun (1962) predicted an average elevation increase-to-shoreline loss ratio of 100:1. According to this premise, a 20-centimeter increase in sea level (one prediction for the next 50–100 years) will result in a 20-meter encroachment of the land-water interface. Bruun's rule has been criticized as being overly simplistic (Walkden and Dickson, 2006). It is, however, probable that the erosion rate will greatly increase as sea level rises (Spyres, 1999). Although the processes that govern sea level rise are not well understood (Karl et al., 2008), it is interesting and somewhat alarming to note that the actual measured rate of sea level rise is greater than existing models have predicted (Domingues et al., 2008). Given the relative narrowness of the current sand beach (approximately 90 meters after renourishment), it is merely prudent to protect this valuable asset if we wish the sea wall to persist in the future.

MSU Experimental Beach Sites on the Mississippi Gulf Coast

Mississippi State University has two demonstration sites located in Biloxi, Mississippi. The first of these is a 1.2-hectare site created in 1996 at Miramar Road. The work was initially undertaken to determine whether a salt marsh could be used to replace unsightly storm drains that occur about every 200 meters along the beach. A storm drain at the site was broken at midbeach and opened, creating a storm and tidal pool that emptied roughly three-quarters of the way from the sea wall to the water line. The banks of the tidal pool and the section at the edge of the Mississippi Sound were reinforced with erosion control matting and planted with emergent smooth cordgrass and salt hay (*Spartina alterniflora* and *Spartina patens*). The area surrounding the pool and some sections of the midbeach were planted with dune grass (*Uniola paniculata*), saw palmetto (*Serona repens*), and long-leaf pine (*Pinus palustrus*).

Many of the initial plantings of beach and emergent plants were lost in the first 2 months due to beach erosion processes. Storm water runoff carried unstabilized sand down the beach. The transported sand covered much of the dune grasses, some salt hay, and some smooth cordgrass. Wave energy washed away the remainder of the smooth cordgrass that had been planted in the tidal zone. About a third of the plantings, located on one side of the pool and in patches in the midbeach area, survived these initial perils. These plants, once established, grew and flourished for years on the site.

The loss of two-thirds of the initial planting changed the thrust of the project from storm drain replacement to erosion control. Subsequent plantings focused on five factors:

- Methods to establish emergent plants in the tidal zone to inhibit erosion at the beach water interface;
- Methods to dissipate the energy of overland water flow due to storm water runoff;
- Methods to enhance the survival of plants immediately after planting;

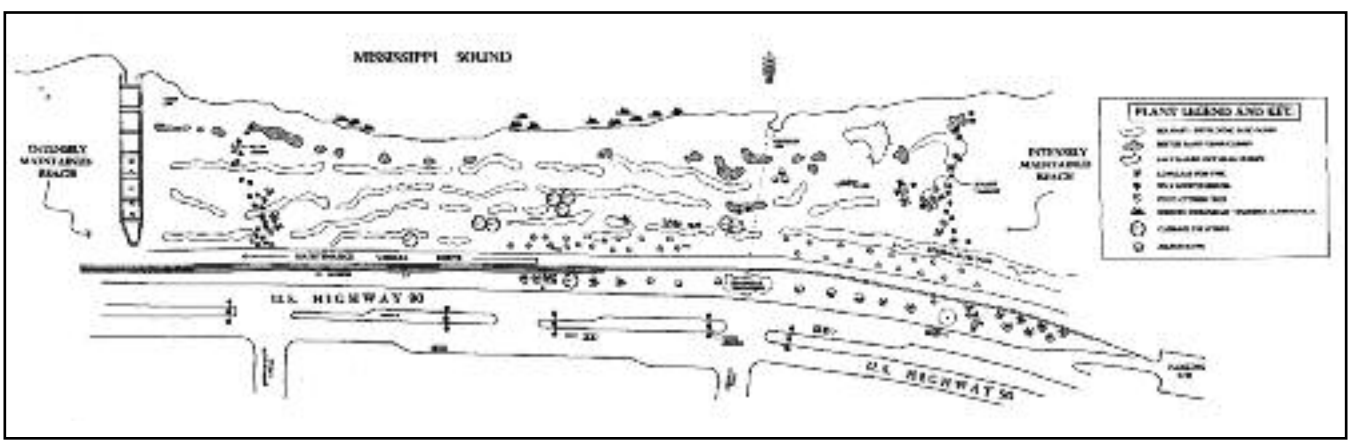

Figure 6. Planar view of the 1.2-hectare experimental site located in Biloxi, Mississippi, before Hurricane Katrina (August 2005).

- Methods to prevent storm water runoff and stabilize the surface layer of sand; and
- Methods to reduce wind erosion.

These efforts initially met with mixed success. Over the next 10 years, however, techniques were developed in each of these areas (outlined in subsequent sections) that have met, or shown great promise of meeting, all of these goals.

Figure 6 shows the Miramar Road experimental site as of 2005. The initial planting was in the vicinity of the storm drain. Initial up-beach plantings were designed to protect lower beach plantings from sand transported by storm water runoff. During subsequent years, as funding became available, additional parts of the 1.2-hectare site were planted. All plants used were native to the Mississippi beach environment. By 2002, as described in a subsequent section, smooth cordgrass (*S. alterniflora*) had been established at the beach-water interface. Once established, these emergent plants expanded steadily, despite numerous high-energy events, until they covered an area of approximately 0.1 hectare.

Figure 7. Miramar experimental site after Hurricane Katrina, Sept. 6, 2005 (Courtesy NOAA).

Other than a continuous expansion of the small salt marsh, the site remained relatively unchanged during the period 2002 to 2005. In August 2005, Hurricane Katrina struck the northern Gulf of Mexico. The principal effect of the hurricane on the Miramar experimental site was deposition of vast amounts of sand. The piled sand was so extensive that heavy equipment was required to clear the highway just above the site (Figure 7). It is not possible to tell whether the planted beach was in any way responsible for the sand deposition that occurred, but its occurrence was suggestive.

The effect of the hurricane on the site varied with position. On the upper beach, the dense root mass of the established dune grasses remained largely intact. Shoots from the root mass quickly grew through the covering sand. Some of the shrubs and forbs also came back. All of the trees were lost, although it was not clear whether the loss was due directly to the hurricane or whether they were lost during the removal of the piled sand. By the following year (summer 2006), the upper beach was much as it had been before the storm with the exception that about half of the shrubs and all of the trees were gone.

Vegetation on the midbeach was almost entirely lost. It did not appear that sand coverage at midbeach was any greater than on the upper beach, but there was not recovery of the dune grass on midbeach. It is possible that wave action may have directly affected the root mass at midbeach or perhaps some other factor was responsible. It appeared, through much of the project, that midbeach grass growth was less vigorous and less uniform than on the upper beach. It is likely that the occasional overwash of the midbeach, and the greater exposure to strong winds, may have made the midbeach a more stressful environment. The exception to this trend was the five Louisiana palms (*Sabal palmetto* "Louisiana") that were planted midbeach. These came through the storm largely intact. They have a dense fibrous root mass that appeared to protect the palms from the effects of wind and waves.

The 0.1-hectare salt marsh was sheared by the storm, leaving a roughly 5-centimeter stubble at the sand surface. The root mass was completely intact, but recovery over the following year was sparse and partial. It appears likely that the hurricane occurred before the plants began to divert energy to the rhizomes for winter storage (Gallagher et al., 1984). Consequently, most of the *S. alterniflora* starved during the subsequent months. The following spring, sparse growth occurred near the middle of the largest section of the marsh and nowhere else. Although the recovery was not robust, it is likely that the marsh would have grown back over time. The renourishment that followed in 2007 extended the beach approximately 30 meters, covering the remnants of the marsh.

Experiences at the Miramar experimental site illustrated several factors:

- Most of the native plants, once established on the beach, will persist despite the regular occurrence of large storms and other high-energy events.
- Survival will not be 100%. Some portions of the beach may see higher loss rates than other portions. Some plants will be lost over time at all parts of the beach. Regular maintenance at a beach using this type of bioengineering must include provision for some replacement of plants as they are lost.
- Beach plants such as *U. paniculata* and *S. patens* will virtually halt wind erosion and help reduce erosion due to storm water runoff. This will be described in later sections.
- Emergent beach plants such as *S. alterniflora*, once established, will inhibit erosion at the beach-water interface. This will be described in a later section.

A second demonstration site, at the Schooner Pier in Biloxi, was created in 2006 to test and demonstrate the efficacy of some of the approaches developed at the Miramar site. This site has, so far, proven extremely successful:

- A nearly 100% rate of plant survival has been achieved.
- Dune growth has exceeded expectations.
- Emergent plants appear to be growing into the tidal zone.

The site is regarded as extremely attractive and a real asset to this important tourist destination.

Native Herbaceous and Tree Species Found on the Demonstration Sites

The phrase "beach environment," as used in this bulletin, includes everything from the intertidal zone to the beginning of the inland vegetation. The different parts of the beach environment "share a set of environmental characteristics (wind, sand deposition and erosion, substrate mobility, salt exposure, flooding, drought, and nutrient deficiency) that greatly affect seed germination, seedling establishment, and adult performance" (Hesp and Martinez, 2007). There are additional challenges for plants in this habitat (Ripley, 2002):

- On clear days, solar radiation can be very high, including direct and reflected components;
- Very high afternoon sand temperatures and large diurnal temperature changes in summer;
- Low water retention of sand, leading to large changes in water content over short periods;
- Exposure to unprotected wind from the sea, which not only affects plants directly but also indirectly by buffeting the plants with sand and by influencing evaporation rate; and
- Exposure to salt spray and occasional (for land vegetation) immersion in salt water.

Before 2002, only 10 species of plants, shrubs, and trees were planted on the Miramar experimental site. During 2002, a site survey revealed that 42 additional beach species ("volunteers") had colonized the site (Table 2).

Beach plants have a number of adaptations that help them to survive and spread in the harsh beach environment. Some representative examples are described below:

- Sea Oats (*Uniola paniculata*) — Dunes – Tolerate salt spray, short periods of inundation by saltwater, burial by sand (burial actually promotes deep root growth), and droughts. Root and rhizome network holds sand in place. Stems capture blowing sand. (Fine, 2000).
- Dwarf Wax Myrtle (*Myrica pusilla*) — Upper beach – Waxy coating helps prevent desiccation; ability to fix nitrogen is useful in the beach environment, which is chronically nutrient poor (de la Garza, 1999).

- Longleaf Pine (*Pinus palustrus*) — Edge of coastal maritime hammock (upper beach) – Much more resistant to hurricane damage than other regional pine species (Stainback and Alavalapati, 2004).
- Live Oak (*Quercus virginiana*) — Edge of coastal maritime hammock (upper beach) – Resistant to salt spray and high levels of soil salinity; resistant to hurricane damage (Harms, 1990).
- Smooth Cordgrass (*Spartina alterniflora*) — Emergent marsh plant that resists erosion once established and tolerates low oxygen and prefers the ammonium form of nitrogen characteristic of the intertidal zone (Woodhouse et al., 1976).
- Salt Hay (*Spartina patens*) — High marsh and beach – Tolerates occasional inundation by storm tides; traps sand and grows well as beach elevation increases (Fine, 2005; Wilkes, 2007).
- Bitter Panic Grass (*Panicum amarum*) — Dune, midbeach – Resists wind erosion; covering stems promotes rooting and new plant growth (BPMC, 2006). Transplants more readily than sea oats (Lamphere, 2006).
- Yaupon Holly (*Ilex vomitoria*) — Edge of coastal maritime hammock (upper beach) – Tolerates salt spray, constant wind, full sunlight, and high temperatures; produces fruit that are eaten by wildlife (Coladonato, 1992).
- Saltgrass (*Distichlis spicata*) — Low beach to high beach – Tolerates a wide range of soil salinities and pH levels; its extensive system of rhizomes and roots form a dense network that inhibits wind and water erosion (Hauser, 2006).
- Sea Rocket (*Cakile edentula*) — Dunes – Has floating seeds that act as a dispersal mechanism; burial by sand promotes both growth and reproduction (Zhang and Maun, 1998).

These are merely representative samples of the many adaptations that allow beach environment plants to persist and thrive in difficult surroundings. The existence of such characteristics makes native vegetation the best choice for stabilizing and protecting a threatened habitat.

Table 2. Native Grasses, Forbs, Shrubs, and Trees Found on the Miramar Experimental Site in 2002.
Planted Species
Spartina alterniflora (Smooth Cordgrass)
Spartina patens (Salt Hay)
Panicum amarum (Bitter Panic Grass)
Unolia paniculata (Sea Oats)
Ilex vomitoria (Yaupon Holly)
Iva frutescensi (Marsh Elder)
Myrica pusilla (Dwarf Wax Myrtle)
Pinus palustrus (Longleaf Pine)
Quercus virginiana - (Live Oak)
Serona repens (Saw Palmetto)
Volunteer Species
Batis Maritima (Saltwort)
Briza minor (Quaking Grass)
Cakile edentula (Sea-rocket)
Cassia aspera (Partridge-pea)
Cassia fasciculate (Partridge-pea)
Cenchrus incertus (Coastal Sandbur)
Centrosema virginianum (Climbing Butterfly-pea)
Clitoria mariana (Butterfly-pea)
Croton glandulosus (Croton)
Croton punctatus (Silver-leaf Croton)
Cyperus esculentus (Yellow Nutgrass)
Cyperus haspen (Leafless Sedge)
Diodia teres (Rough Buttonweed)
Distichlis spicata (Saltgrass)
Erigeron vernus (Robin's-plantain)
Eustachys petraea (Fingergrass)
Gaillardia pulchella (Firewheel)
Helenium autumnale (Sneezeweed)
Helianthemum corymbosum (Rock-rose, Sun-rose)
Heterotheca subaxillaris (Camphorweed)
Hydrocotyle umbellate (Marsh Pennywort)
Ipomoea brasiliensis (Railroad-vine)
Ipomoea stolonifera (Fiddle-leaf morning-glory)
Lantana camara (Shrub-verbena, Lantana)
Odontonychia corymbosa (Whitlow-wort)
Oenothera laciniata (Cut-leaved Oenthera)
Opuntia humifusa (Eastern Prickly-pear)
Paspalum notatum (Bahia Grass)
Phlox drummondii (Annual phlox)
Richardia brasiliensis Gomez (Mexican-Clover)
Rhynochosia minima (Climbing Rhynchosia)
Rotala ramosior (Toothcup)
Rubrus argutus (Blackberry)
Scirpus americanus (Swordgrass)
Sesbania vesicaria (Bladder-pod)
Sesuvium portulacastrum (Sea-purslane)
Solidago canadensis (Tall Goldenrod)
Solidago sempervirens (Seaside Goldenrod)
Strophostyles helvola (Wild Bean)
Triplasis purpurea (Purple Sandgrass)
Vicia angustifolia (Narrow-leaved Vetch)
Vigna luteola (Vigna or Savi)

The loss of much of the initial planting at the Miramar experimental site due to storm water transport of sand from the upper beach led to the first upper beach plantings. These consisted primarily of sea oats (*U. paniculata*) planted in double lines to initiate dune formation (these dunes are shown along the drain line path in Figure 6). During the period 1996–98, as additional funds became available, additional upper beach plantings were implemented until the entire 1.2-hectare Miramar Road site was planted. By 1998, it was clear that, although recognizable sand dunes were growing, the net effect was raising the elevation of the beach as a whole. In effect, the beach was taking on the quality of a single large dune.

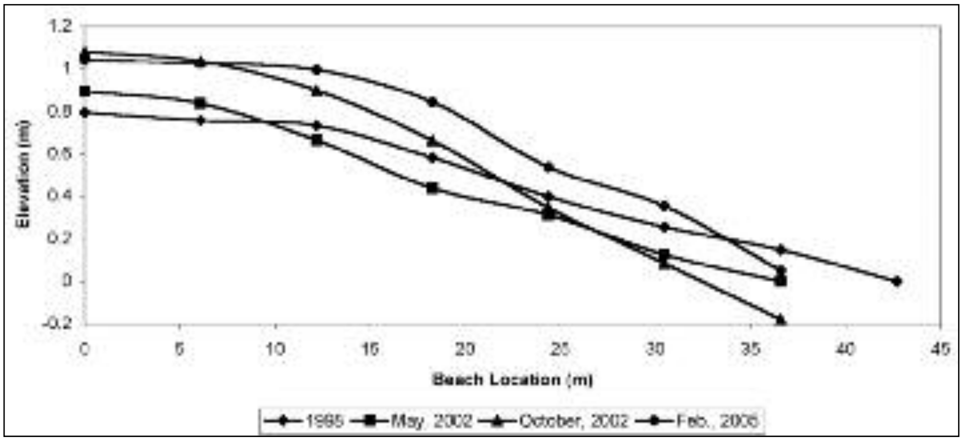

Figure 8. Miramar experimental site profiles, 1998–2005.

This process was documented during the period 1998–2005 in a series of beach elevation profiles. The profiles were based on parallel transects (as few as six and as many as 15, depending on the date) running north to south. Elevations along each transect were taken at approximately 6-meter intervals using a total station instrument. Zero elevation was located approximately at the high-tide line. Figure 8 shows the progression of beach elevation increases during this period. By 1998, the beach had assumed a natural sloping profile, increasing from south to north. During the period from 1998 to May 2002, there was a small elevation increase at the northern end. By October 2002, after a hurricane and a

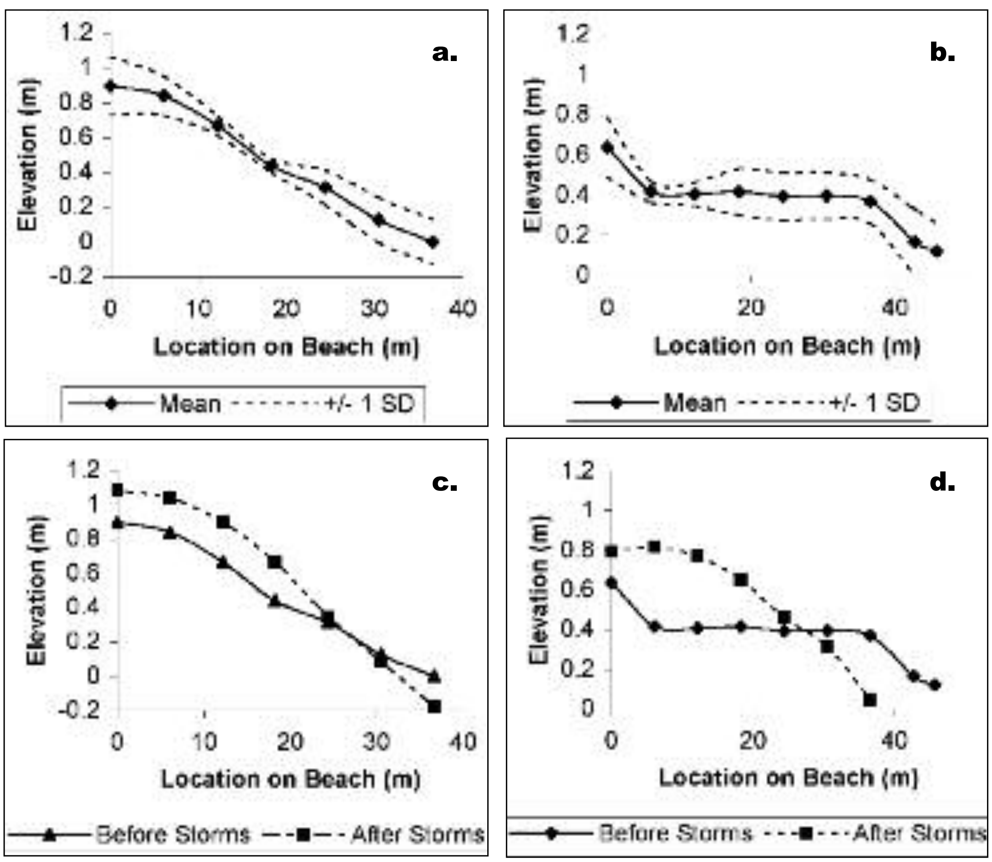

Figure 9. Sand accretion on the Miramar experimental site and the adjacent control site between May and October 2002: (a) experimental site, May 2002; (b) control site, May 2002; (c) experimental site, May and October 2002; (d) control site, May and October 2002.

tropical storm, the elevation showed a substantial increase from upbeach to midbeach. The beach then began to build toward the water, showing a substantial elevation increase midbeach to lower beach by February 2005.

Most sand movement on a low-energy beach is the result of a relatively small number of high-energy events. The vertical growth between May and October 2002 was mainly the result of two large storms (Hurricane Ivan and Tropical Storm Lily). Figure 9 shows the Miramar experimental site and the conventionally managed control site in May and October 2002. The experimental site in May (Figure 9a) has the gradually sloping profile characteristic of a beach that has been allowed to develop naturally. The control site May profile shows the effect of sculpting by heavy equipment (Figure 9b). Upper beach sand on the control site was pushed toward the beach-water interface to extend the beach and thus presents a uniformly flat appearance. Figures 9c and 9d show the experimental and control site profiles before and after the major storms of 2002. The storms increased the maximum elevations and decreased the widths of both beaches, giving the control site a more "natural" profile.

It is possible to use profile measurements to estimate sand gain and/or loss on the beach. The amount of sand added or lost is represented by the area between the profile curves. In Figures 9c and 9d, the upper beach on both the control and experimental sites gained sand due to elevation increase. Both sites lost sand on the lower beach due to elevation decrease and beach shortening. The net gain or loss is represented by the difference in the areas that define gain and loss (Figure 10).

The amount of sand gained or lost can be quantified by calculating the areas of the respective regions of gain or loss and then multiplying the areas by a representative beach length. This is a commonly used land surveying technique (Wolf and Brinker, 1994). For the experimental beach (Figure 9c), the increase was 4.7 square meters, and the decrease was 0.7 square meter, giving a net gain of 4 square meters.

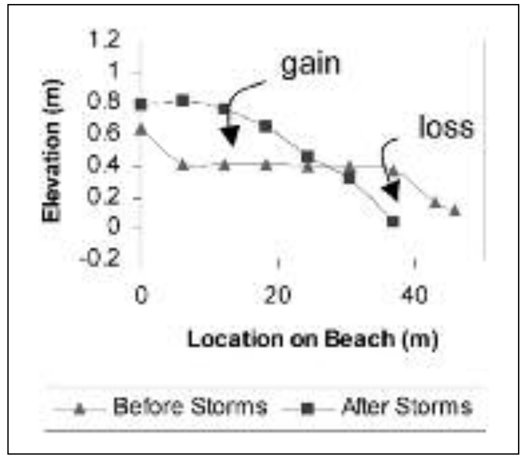

Figure 10. Sand gain and loss based on profile measurements.

For the 300-meter-long experimental site, this represented a net gain of approximately 1,200 cubic meters of sand. On the control site, the increase was approximately 6.8 square meters, and the loss was approximately 2.6 square meters. The net gains for the two sites were nearly identical (approximately 4 and 4.2 square meters, respectively).

These measurements show that there is the potential, under some circumstances, for net beach building to occur. Such processes occur on most of the beach. The historically consistent loss of sand on the 42-kilometer beach may then be due, not to the absence of beach building processes, but to the absence of processes that allow net gains to be conserved. For example, the sand loss on the control site lower beach during May–October 2002 was approximately 2.6 square meters. On the experimental site, the lower beach loss was 0.7 square meter. The nearly fourfold difference appeared to be due mainly to the natural profile of the experimental site and the artificially "pushed out" profile of the control site. During the period 1996–2005, the experimental site consistently gained in elevation. This was a result of practices that not only promoted sand capture, but also retained the captured sand. These processes will be described in the next sections.

Wind is one of the three principal sources of erosion on the 42-kilometer beach, accounting for as much as a third of total sand loss (Schmid, 2003). Wind from the south transports sand over the sea wall onto the adjacent highway and property. Winds from the south and southeast are prevalent for approximately half the year (Jacobson and Rees, 2006). High-energy events such as thunderstorms often have variable wind direction that includes a southerly component (Friend, 2002). The events with the greatest wind energy are tropical storms and hurricanes, which generally pass south-to-north over the coast (Schmid, 2003).

Wind transports sand when wind shear (i.e., the frictional force of the wind on the beach surface) overcomes the inertia of sand grains. When shear exceeds the threshold wind shear velocity (i.e., the velocity at which the sand grains begin to move), then erosion will occur. The use of native plants to reduce or eliminate wind erosion is based on the effect that the plants have on the wind velocity profile between the surface of the sand and the tops of the plants.

The effect of native plantings on wind erosion can be demonstrated theoretically and by field measurements. We will first show the mathematical basis for this practice and then report the field observations from the demonstration site that supported the theoretical predictions.

Studies of the effects of wind erosion on vegetated and unvegetated surfaces are often based on the equations that follow. The parameter "roughness density" (λ, unitless) is calculated (Gillies et al., 2006)

$$\lambda = \frac{(n * d * h)}{S}$$

where *n* is the number of plants, *d* is the average plant diameter, *h* is the average plant height, and *S* is the planted surface area. Roughness density provides a measure of the surface area in opposition to wind transport by relating surface area per plant (d*h) to plant density (n/S).

The aerodynamic roughness length, z_o, is the height above the surface at which friction causes the average wind velocity to become zero (Zhang et al., 2004). For a completely smooth surface with no plants, z_o would equal zero (a thin stagnant layer of air molecules lays just above any surface). Since natural surface irregularities make $z_o > 0$, much field research has been done in an attempt to determine roughness lengths in real systems. Marticorena et al. (1997) suggested that for $\lambda < 0.11$,

$$\log_{10}(z_o / h) = 1.33 \log_{10} (\lambda) - 0.03$$

Using this equation with average plant height and the roughness density, it is possible to calculate the aerodynamic roughness length (z_o), which gives us the height above the surface at which the energy dissipating effects of the plants creates a stagnant layer.

It is well accepted that the velocity, within the elevation limits influenced by the planted region, has a logarithmic profile (Tennekes, 1972). The most commonly used equation to express this is (Zhang et al., 2004)

$$u(z) = (c_s/0.4) \ln(z/z_o)$$

where u(z) = velocity (cm/s), c_s = shear velocity (velocity required to initiate erosion, cm/s), "0.4" is the von Karmon constant, z = elevation (cm), and z_o = the roughness length (cm). The shear velocity for beach sand is approximately 10 to 20 centimeters per second (Cornelis et al., 2004)

Table 3 shows the calculated values and constants used to compare a beach planted at approximately the density of our experimental sites with an "unplanted" (actually, a very sparsely planted) beach. Appendix I contains the calculations used in this comparison. Figure 11 summarizes the results of these calculations. Notice that the plants decrease the energy of the wind at all levels up to the height of the plants. This explains the resistance of sand already in the planted area to wind transport. It also explains why sand blowing into the planted region has a tendency to drop out of the wind stream when it reaches the planted area. Sand transport is largely saltatory: the sand moves in a series

Table 3. Values Used to Compute Velocities in Planted and Unplanted Beach Sites.

Variable	"Unplanted"	Planted
n	1	54
d (m)	0.005	0.005
h(m)	0.50	0.50
A(m^2)	3.72	3.72
c_s (m/s)	0.2	0.20
λ	$6.7(10)^{-4}$	$3.6(10)^{-2}$
z_o (m)	$2.8(10)^{-5}$	$5.6(10)^{-3}$

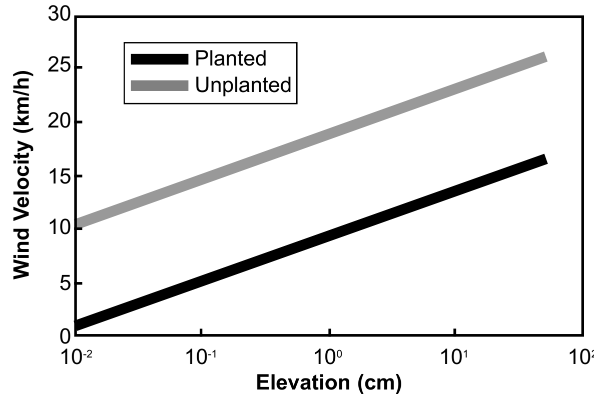

Figure 11. Semi log plot of predicted wind velocity above the sand surface.

Table 4. Results of Leatherman Tube Measurements.

Sampling date	Mean sample mass	Range (max/min)	Number of observations
	g	*g*	
	Experimental Site		
5/22/02	0.272	0.076-0.776	6
5/31/02	1.851	1.432-2.567	6
6/06/02	0.459	0.009-1.700	6
6/09/02	1.519	0.238-4.909	6
6/10/02	0.754	0.520-1.220	6
	Control Site		
5/22/02	7.863	2.11-14.99	3
5/31/02	201.28	13.15-578.30	4
6/06/02	127.45	53.86-197.75	5
6/09/02	320.88	18.10-488.70	5
6/10/02	54.54	20.95-95.35	6

of short hops rather than continuously. Sand that is "hopping" through the planted area will hop less far. Sand that drops into the planted zone will remain there. This is the mechanism that plants use to form dunes and to inhibit wind erosion beyond the planted location.

The efficacy of plants to inhibit wind erosion on the beach was measured on the 1.2-hectare Miramar site. In order to measure wind erosion directly, Leatherman tubes (Leatherman, 1978) were constructed in the biological engineering shop and used to compare sand transport northward on the experimental and control sites. Six tubes (Figure 12) were located at approximately 15-meter intervals near the northern end of the Miramar experimental site and a control site (conventionally managed) just to the west of the experimental site. The tubes were placed on the sites with approximately 1 centimeter of tube surface exposed above the sand surface to ensure that most collected sand was due to wind transport. The tubes were sampled periodically (periods of 1 day to 2 weeks) through the months of May and June 2002. Disturbance of some tubes on the control site was relatively common during May–June. After July 1, sampling was discontinued because high beach traffic led to regular disturbance of all tubes on the control site.

Sand samples were air dried after collection. The mass of sand from each tube was measured in the MSU Biological Engineering Water Quality Laboratory using a laboratory balance. Sand masses from the control and experimental sites were then compared.

Table 4 summarizes the results of the Leatherman tube tests. An analysis of variance was performed on

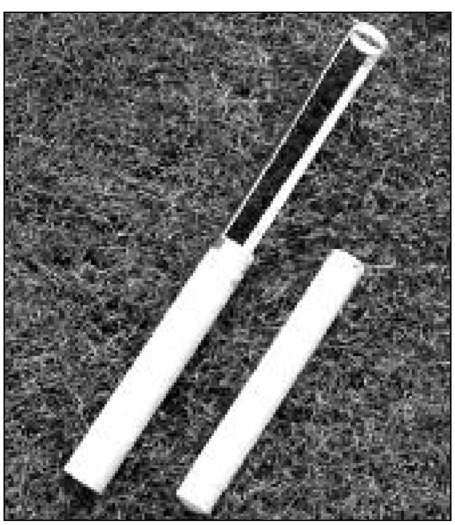

Figure 12. Leatherman tubes used to measure wind transport of sand on the beach.

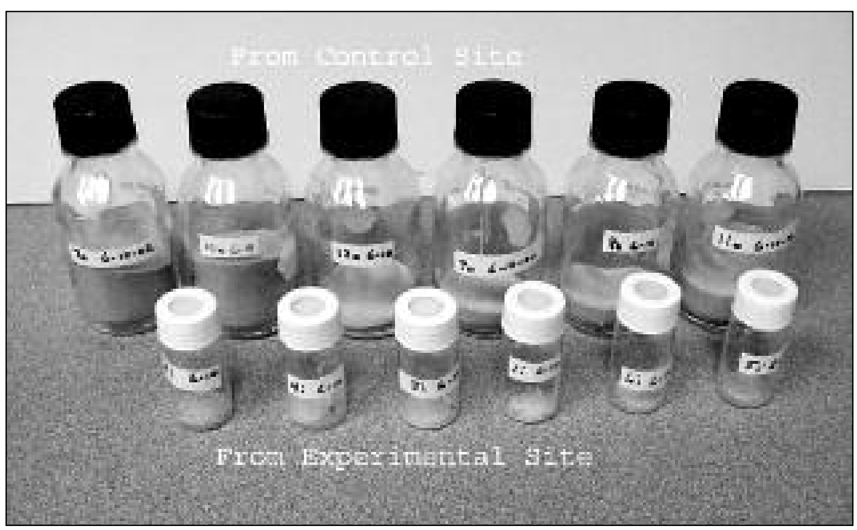

Figure 13. Sand captured in Leatherman tubes on the experimental site (small bottles) and on the control site (large bottles) over a 15-hour period.

these data using a factorial GLM procedure (SAS, 2002). Sand transport was significantly greater on the control site than on the experimental site ($P < 0.01$). Figure 13 illustrates the magnitude of the mass transport differences measured on the experimental and control sites.

Both the theoretical predictions and the *in situ* measurements indicate that plantings do an excellent job inhibiting wind erosion. It is important to note, however, that the exceptionally impressive results of the *in-situ* measurements may not been solely due to the effects of the plants on the wind field. The heavy equipment used to groom and rake the beach was excluded from the experimental site. On the control site, the sand was routinely fluffed and otherwise destabilized by the mechanical raking process. It can be argued that this destabilization contributed to the sand transport on the control site. As will be shown in the next section, the heavy equipment alters the physical characteristics of the beach in other ways as well.

NATIVE PLANTS AND EROSION DUE TO STORM WATER RUNOFF

The use of heavy equipment to rake and groom the beach has the obvious effect of fluffing and otherwise destabilizing the surface sand. As described in the previous section, this exacerbates wind erosion. It also makes the beach vulnerable to erosion caused by storm water runoff.

This was first noticed on the Miramar site after the initial planting when plant loss came not from coastal waves and currents (as expected) but from the vast amount of sand transported down beach after a large rainstorm. The transported sand buried many of the plants that had been planted just a few weeks previously.

After this event, researchers noticed that water tended to pond on both the newly planted site and on the adjacent conventionally managed site after storms. Upper beach plantings were made at the Miramar site to stabilize the sand and prevent a repetition of the runoff that had covered much of the first planting (Figure 6). The upbeach plantings had the immediate effect of decreasing the energy of the runoff, thus decreasing the amount of sand transported by the storm water. Over the next few years, the upper beach plantings resulted in beach building. The elevation of the beach increased as plants captured and held the sand that blew upbeach and that washed in during storms (Figure 8).

By 2002, researchers noticed that the ponding, which still occurred on the adjacent, conventionally managed site to the west, no longer occurred on the experimental site (Figure 14). This led to a series of measurements on the experimental site and the conventionally managed "control" site to ascertain the reason for the perceived differences.

Figure 14. Experimental site (foreground) and control site showing ponding after a storm.

Compaction

The amount of sand compaction affects the route taken by storm water runoff. Less compacted sand is more permeable than compacted sand, allowing greater infiltration of precipitation. This is important because surface runoff can be highly erosive. On the 42-kilometer beach, surface runoff carries sand toward the Mississippi Sound, where it can be carried away by waves and currents.

Compaction surveys were conducted May 18 and June 9, 2002. Compaction was measured on the experimental and control sites using a cone penetrometer (Spectrum, SC-900). The initial survey was preliminary and limited to three transects on the experimental site and three on the control site. The transects were oriented north-to-south from a point 10 meters south of the sea wall to the water's edge. The transects were parallel and spaced at approximately 12-meter intervals.

Transect stations were 6 meters apart. The preliminary survey was conducted 1 day after a heavy rainstorm.

The second survey was more extensive, consisting of six transects on each site. Transect and station intervals were 12 and 6 meters, respectively. Transects again ran from a point 10 meters south of the sea wall to the edge of the Mississippi Sound. This compaction survey was conducted after an extended dry period on the beach.

Results from the second, more extensive survey are summarized in Figure 15. An analysis of variance was performed using a factorial GLM procedure (SAS, 2002). Compaction at all tested depths was significantly greater on the control site than on the experimental site ($P < 0.01$).

The differences in compaction are not surprising. It has long been known in agriculture that continued use of heavy equipment compacts subsoil beneath the plowed depth (Frisby and Pfost, 1993; Petersen et al., 2003). Compaction due to frequent use of heavy equipment is known to reduce infiltration and increase erosion, and it can lead to the ponding observed on the 42-kilometer beach (Kok et al., 1996; Daum, 1996).

Figure 16 compares compaction for the experimental and control sites after a period of heavy rain and after an extended dry period. A factorial analysis of variance revealed that rain significantly increased compaction on the experimental site ($P < 0.01$). The same test performed on the control site showed no difference in compaction as a result of precipitation ($P > 0.05$). The compaction of the experimental site after rainfall was then compared with the lumped rain/no-rain compaction on the control site. The compaction of the experimental site after rainfall was significantly less than that of the combined data from the control site ($P < 0.01$).

The compaction results provide an interesting insight into the physical characteristics of a mechanically groomed beach versus a beach that is allowed to develop naturally. The physical character of the beach that has been allowed to capture sand and grow vertically appears to be sensitive to the presence of interstitial water. The mechanically groomed beach, repeatedly compressed by the passage of heavy equipment, may have insufficient interstitial space to allow transport of much water into the sand beneath the surface. The observed ponding and low infiltration rates (see next section) support this conclusion. Figure 16 also showed an interesting response at a depth of 30 centimeters. After rainfall, mean compaction dipped below the dry measurements. This appears to indicate some sort of interaction between depth and rain (a thixotropic response at the water table?). Corollary measurements to resolve this were not made.

Infiltration Rate

Water infiltration on the experimental and control sites was measured directly during June 2002, using a double-ring infiltrometer (Turf-Tec International). The time required, as well as the difficulty of measuring infiltration, precluded the use of transects. Instead, multiple replicates were made at three locations on each site: near the dune line, at midbeach, and just to the north of the beach berm (i.e., the break in the beach slope caused by tides and waves). These locations were

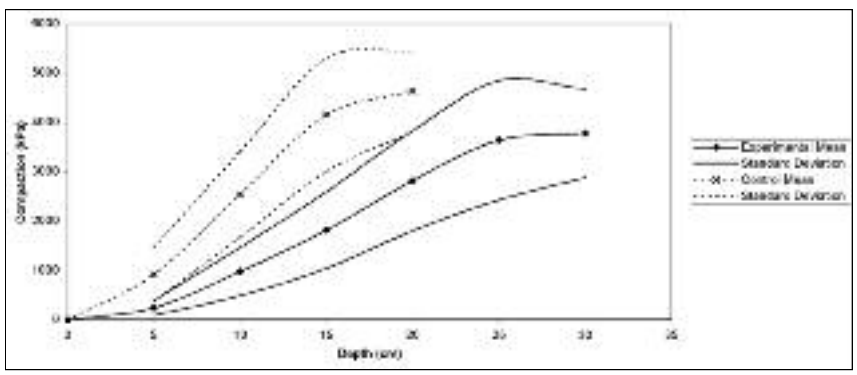

Figure 15. Compaction measurements from the control and experimental sites.

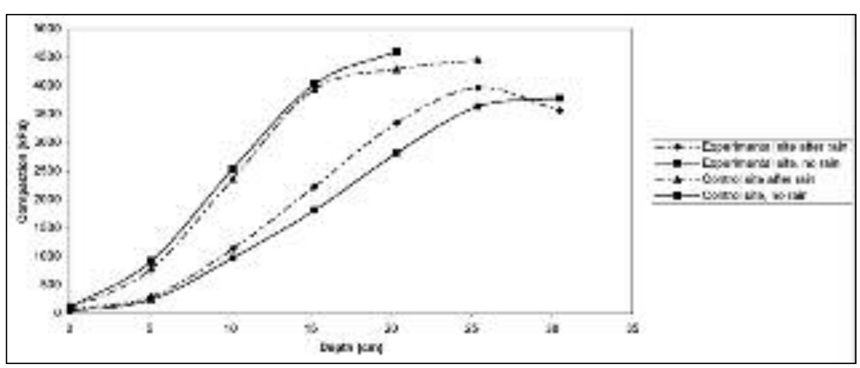

Figure 16. Compaction on the Miramar experimental site and the control site after a dry period and a period of heavy rain.

chosen because they had differing exposures to beach processes. Sand near the berm was assumed to be most often reworked by wave action. Sand near the dune line was assumed to be relatively protected from heavy equipment on the control site, and sand at midbeach was assumed to be most vulnerable to the compacting effects of heavy equipment on the control site. Results of these measurements are shown in Table 5.

The differential compaction measurements suggested that water infiltration rate would be greater on the experimental site than on the control site but did not convey information about the magnitude of the difference. A factorial analysis of variance on the infiltrometer measurements indicates that infiltration on the experimental site was significantly greater than that on the control site ($P < 0.01$). Location on the beach (i.e., upper, mid-, or lower beach) was not a significant effect ($P > 0.01$).

Although position on the beach was not a significant determinant of infiltration, it is interesting to compare the experimental and control sites by position. Near the dune line (upper beach), mean infiltration rate on the experimental site was approximately 2.5 times the magnitude of that measured on the control site. At midbeach, the ratio of infiltration rates was nearly 6:1. Near the beach berm, water infiltration on the experimental site was nearly nine times that of the control site.

The ratio of infiltration rates near the dune line was the smallest of the three beach zones considered. This was consistent with the assumption that the extreme upper beach on the control site would experience the smallest amount of traffic from heavy vehicles and hence show the least compaction.

The highest ratio occurred at the berm, very close to the beach-water interface. This was surprising as it was assumed that sand closer to the water's edge would be reworked most frequently by wave action on both the control and experimental sites and that this would result in fairly consistent infiltration rates on both sites. This was clearly not the case. A possible explanation is that both sites have experienced continuous net loss of sand at the beach-water interface; this has been historically the case on the 42-kilometer beach. The berm had been moved northward since the previous renourishment. As a result, the sand at the berm may well have been north of the berm a short time before, subject to the same compaction as the midbeach sand. The nearly identical infiltration rates on the middle and lower control locations tended to support this explanation. The lower experimental site, in contrast, had the greatest infiltration rates of all tested locations. It is not clear what is different about the lower beach on the control site and the lower beach on the experimental site. The absence of heavy equipment is certainly a factor. Other factors are yet to be determined.

Infiltration at the midbeach was approximately six times greater on the experimental site than on the control site. This was consistent with expectations based on compaction differences. The greater infiltration rates on the experimental site explain the absence of the ponding that was observed on the mechanically groomed beach. As mentioned, surface ponding is an indicator of the potential for storm-water-related erosion when downbeach flow occurs.

Table 5. Infiltration Rate Measurements on the Experimental and Control Beach Sites.[1]

Location on beach	Mean infiltration rate	Standard deviation	Number of observations
	cm/s	*cm/s*	
Experimental Site			
Upper	9.6	1.4	3
Middle	8.3	2.0	8
Lower	13.4	4.8	3
Control Site			
Upper	3.9	1.4	5
Middle	1.4	Range = 0.2 – 3.8[2]	8
Lower	1.5	0.4	6

[1]Upper beach = near the dune line; Lower beach = just to the north of the beach berm; Middle beach = roughly equidistant from the beach berm and the dune line.
[2]Non-normal distribution (six observations less than 1.25 cm/s; 2 observations 2.55-3.80 cm/s).

The history of the 42-kilometer beach for the last 50 years has been a relatively steady net loss along most of the beach-water interface (Schmid, 2003). Schmid (2003) estimated that two-thirds of the total sand loss that occurs is due to current and wave action. As described previously, erosion accompanying storm water runoff on the conventionally managed beach appears to conduct sand to the wash zone, thus providing an efficient conduit for sand loss from the entire beach width.

Although the beach is considered "low energy" with relatively small waves predominating most of the time, it is estimated that the beach experiences 20–30 events per year that markedly increase wave energy. These events include a relatively small number of serious storms. Most periods of higher wave energy are associated with the passage of winter cold fronts (Harwood et al., 2005). It appears that these events account for most of the periods of net sand loss.

As described previously, native beach plantings on this low-energy beach can effectively build the beach vertically. Although vertical beach growth may prolong the time interval between successive sand renourishment projects, the encroaching wave wash zone will inevitably erode upper beach plantings, ultimately making renourishment necessary.

The key to greatly prolonging the interval, or perhaps even halting erosion, is establishment of emergent marsh plants along the beach-water interface. *Spartina alterniflora* (smooth cordgrass) is the dominant low marsh species on the northern Gulf Coast. Smooth cordgrass is the most popular plant used in the Southeast to protect shorelines. Its dense network of roots and stems reduces shoreline erosion and traps suspended sand and sediment (NRCS, 2006; Wiegert and Freeman, 1990).

Salt marshes generally occur in protected estuaries where wave energy is relatively low. On the Mississippi coast, facing the sound, stands of *S. alterniflora* are very rare, despite the wave-dissipating presence of the barrier islands. Because there are no unprotected stands on the Biloxi-Pass Christian beach, it is easy to assume that the wave energy is simply too great to allow *S. alterniflora* to survive. Wiegert and Freeman (1990) point out that the most critical time for salt marsh plants is during their establishment:

> *Apparently, once the marsh has developed in a protected environment, subsequent shifts in barrier sandbars and exposure to the open sea need not result in the immediate destruction of the marsh. It may persist for decades or centuries …*

This question was investigated at the Miramar Road experimental site. During the initial planting in 1996, erosion control netting was used to protect the root zone of *S. alterniflora* planted at the high-tide line. The netting protected the root zones of the plants, but the stems and leaves above the sand surface received so much mechanical damage that the plants quickly died. Attempts were made to establish plants at the midtide and low-tide lines, both with and without some form of structural protection. Although some of these persisted for several months, the stand never developed the dense vegetated surface zone and interlocking roots that characterize a young marsh that may persist. All of the plants ultimately died.

In 2001, during a renourishment project, the Harrison County Sand Beach Commission director allowed workmen to use dredged sand to shape a protected cove within which both nursery-grown and transplanted *S. alterniflora* were planted (Figure 17). The constructed levee was not intended as a permanent feature. It was intended to protect the plants long enough to

Figure 17. The artificial "cove" constructed as a breakwater during the 2001 renourishment.

Figure 18. The growing salt marsh at the Miramar experimental site showing protection and/or building of the beach edge.

and growth of the created marsh appeared to support the contention of Wiegert and Freeman (1990) that a marsh may persist in surprisingly high-energy environments provided that plant establishment can occur.

Based on these findings, it appeared that *S. alterniflora* establishment did not require a protected intertidal environment, but rather it could be accomplished by planting just above the wave zone and allowing rhizomes to penetrate the wave zone from the beach side. This approach was tested at the Schooner Pier experimental site. Nursery-grown, 10-centimeter containers of *S. alterniflora* were planted at 1-meter intervals just above the wash zone. They were fertilized with 1.5 grams of 14-14-14 Osmocote at planting. The sand just out of the wash zone was naturally always damp. Within 3 months, the plants began to send out rhizomes towards the water's edge (Figure 20). At the time of writing, these plants appear to be forming the basis for a small consolidated marsh at the Schooner Pier site.

allow root development and growth to occur. The plants were placed in the protected cove and on the beach, just above the wave zone. The cove lasted for 8 months. When the levee was breached, the entire feature quickly disappeared, along with practically all of the planted *S. alterniflora*. The lone exceptions were two stands of nursery stock that were planted above the wave zone. These stands had sent rhizomes into the wave zone, which had, in turn, sent up new shoots. At the time that all protection disappeared, the two small planted areas had grown to resemble small consolidated stands, each approximately 2 square meters (Figure 18).

Between June 2001 and August 2005, the experimental site experienced five major storms in addition to many other smaller-scale, high-energy events. During this time the small stands persisted and grew. By the time of Hurricane Katrina (August 2005), the created marsh had a total area of approximately 1,000 square meters (Figure 19). The survival

Figure 19. The salt marsh at the Miramar experimental site (July 2005).

Slowing or halting erosion at the beach-water interface is a key element in beach protection. Upper beach plantings have been shown to lead to vertical beach growth and sand conservation. However, effective biological armoring requires viable protection at the beach edge. The roots of the marsh consolidate sand and sediment at the water's edge, while the stems and leaves dissipate wave energy. The small marsh at the Miramar experimental site provided protection for the beach directly behind it, slowing sand loss at the interface and possibly allowing beach growth on the landward side (Figures 18 and 19). It is likely, although not yet shown, that an established salt marsh at the water's edge would provide effective protection against shoreline erosion over extended distances along the beach.

Figure 20. *Spartina alterniflora,* planted out of the wave zone. Inset: plants sending rhizomes toward the water.

ENHANCING PLANT SURVIVAL

The beach environment is harsh, and the survival rate for young plants is very low under natural conditions. Once established, however, native plants are well adapted to persist for considerable periods. For grasses, a well-established root zone will usually regenerate even if surface vegetation is removed due to natural or man-made events. This was demonstrated after Hurricane Georges in 1998, when debris and then human clean-up scraped the beach to the sand level. *Uniola paniculata* (and most other plants) were fully recovered within a year (Figure 21).

An important element in cost-effective native plantings is use of techniques to enhance plant survival during the critical establishment period. There are several techniques that have worked very well on the 42-kilometer beach.

Deep Planting

Deep planting is a key element for ensuring survival of a large percentage (80% or better) of plants. Part of the reason for the low survival of young plants on the beach is the high probability of desiccation (van Wesenbeeck et al., 2007). Sand on a natural beach is well drained, and the organic fraction, which can conserve moisture, is low (Urban-Malinga and Opaliński, 2001). Moisture occurs with increasing frequency the

Figure 21. Miramar experimental site in October 1998 (after Hurricane Georges) and October 1999 (after extensive recovery).

deeper one probes into the sand. Therefore, the deeper one plants, the greater will be the plants' supply of water. The higher organic content, smaller average particle size, and consequent decreased pore space would preclude transport of oxygen to the root zone. Lack of available oxygen is fatal to most terrestrial plants. On a sandy beach, oxygen diffuses deeper into the sand and deeper planting becomes practicable.

Deep planting is a beneficial strategy for all beach plants, including shrubs and trees. The root ball mass of *U. paniculata* is typically placed at least 30 centimeters below the surface to ensure maximum access to available moisture (Figure 22). The same approach is used with *S. patens* when planted upbeach from the wave zone. In both cases, emergence of as little as 15 centimeters of leaves and stems is adequate to provide sufficient energy for growth as the plants become established. *U. paniculata* and *S. patens* were deep planted on the Schooner Pier experimental site. Survival was nearly 100%, and growth was extremely vigorous. Use of the deep-planting technique for *U. paniculata* is consistent with the experiences of the National Resources Conservation Service (Wilkes, 2007). Wilkes (2007) recommends a more shallow planting depth for *S. patens*, but our experience suggests that the deep-planting depth results in better growth and survival due to more reliable access to water on the 42-kilometer beach.

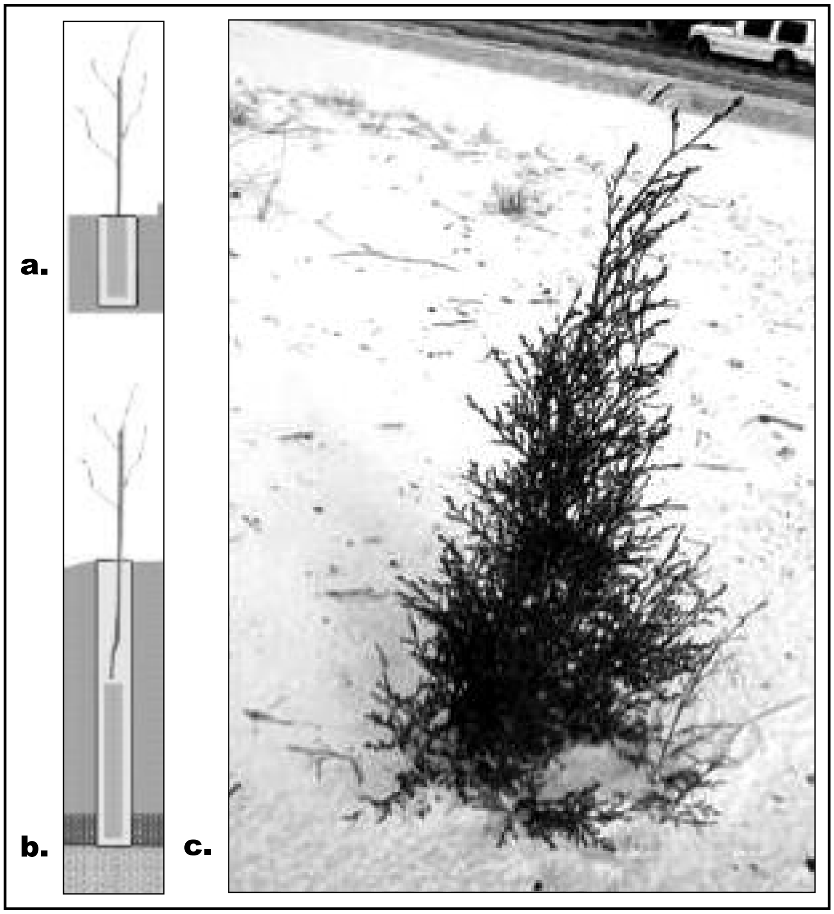

Figure 22. (a) Beach grass planted at conventional depth. (b) Beach grass planted at a depth of 45 cm to enhance survival. (c) A cedar tree planted with its root ball 90 cm below the sand surface.

This approach appears equally effective when applied to trees and shrubs. During 2006, 50 trees and shrubs were planted near the northern extreme of the Miramar experimental site. The trees and shrubs are listed in Table 2. The root balls of the trees and shrubs were placed in holes that were approximately 0.9-meter deep (Figure 22). One year later, 45 of the 50 trees and shrubs were still alive. Six months after that, 39 of the 50 were found alive on the beach. The six additional "mortalities" were not located. The experimental site had recently been groomed after the 2007 renourishment. Although the northern quarter of the experimental site had been spared raking and shaping with heavy equipment, it was clear that the equipment had impinged on the planted area. It appears likely that the six missing trees and shrubs had been accidentally removed during the beach grooming process. At a minimum, survival of the deep-planted trees and shrubs was nearly 80%, which is much greater than the 10–20% survival that would have been expected with planting at conventional depth and in the absence of surface irrigation.

On the Schooner Pier experimental site, all of the trees and shrubs were provided with drip irrigation. Survival was nearly 100% (one tree died for reasons unknown). The condition of the irrigated trees and shrubs was, in general, better than that of the deep-planted specimens. The irrigated stock always had access to adequate water. This was not true of the deep-planted stock. Deep planting does not make water always available. It merely increases the availability of water compared with the availability when planted at a more conventional depth. This is important as irrigation increases the expense of beach plantings and is impossible in many cases (e.g., in places far from an existing water line and on barrier islands). The ability to get enhanced survival in the absence of irrigation is extremely useful in beach plantings.

Not all trees and shrubs fared equally well when deep planted. Longleaf pine (*Pinus palustrus*) and wax myrtle (*Myrica cerifera*) appeared most robust and healthy. Live oak (*Quercus virginiana*) appeared the least vigorous, although most survived. The other species had an intermediate response.

Plant Size

Spartina patens and *Uniola paniculata* are available from nurseries in a variety of sizes (bare root, 2.5-centimeter cones, 5-centimeter containers, and 10-centimeter containers). Although some researchers report superior growth with containers compared with bare root, there does not appear to be consensus elsewhere that larger containers provide superior growth rate and survival. In contrast, our experiences on the Miramar and Schooner Pier experimental sites suggest that the 10-centimeter containers, when planted deeply, show superior growth and survival. This assertion is not supported with measurements and is hence anecdotal.

Spartina alterniflora

As described previously, efforts to establish emergent smooth cordgrass at the Miramar experimental site were unsuccessful until a protected cove was established. Although considered a low-energy beach, the wave energy at the experimental site was nevertheless too great to allow young plants to survive when left unprotected. Even protection using a variety of temporary structures was inadequate. It was the plants that had been initially planted just above the water's edge and then allowed to spread into the water via rhizome growth that survived. At present, this approach appears to be the most practicable method for establishing *S. alterniflora*. By planting just above the wave zone (above mean high tide), adequate root moisture appears to be consistently available. By planting out of the water, it is possible to fertilize more effectively.

As described in a previous section, this approach was attempted at the Schooner Pier experimental site and appears to show great promise for establishing a small marsh there. The fetch at the Schooner Pier site is approximately 1 kilometer. This approach is currently being attempted to reestablish a marsh at the Miramar site as well. Fetch at the Miramar site is approximately 20 kilometers, so the potential for wind-generated overwash is greater there. At the time of this writing, it is not clear whether the additional exposure is a serious impediment at the latter site.

A New Way to Look at the 42-Kilometer Beach

Since the first sand nourishment project more than 50 years ago, the primary goal of beach management has been to maintain its attractive "white-sand" character. This has meant that the encroachment of terrestrial plants has been prevented and the sand surface has been kept clean and soft.

The white-sand beach is familiar to many people, and many people find it a pleasant companion as they travel the adjacent highway. As mentioned previously, the beach is an essential element for preserving the integrity of the existing seawall. But it is a costly to maintain the beach in this way. It is costly from the standpoint of the money required to maintain and renourish it. It is costly from the standpoint of the precious petrochemical resources required in the grooming and renourishment processes. It is costly from the standpoint of the pollutants and greenhouse gases that are produced as a consequence of grooming and renourishment.

The federal contributions to the cost of renourishment appear to be becoming harder to procure. The Mississippi Gulf Coast is not the only region where repeated renourishment projects have occurred. Indeed, a quick Internet search reveals that this phenomenon is occurring along much of the U.S. coastline. Leatherman (1996) predicted that renourishment could become prohibitively expensive as coastal erosion accelerates. This may prove to be the case. The processes that appear to be accelerating renourishment needs (global warming and sea level rise) are not local.

The Mississippi Gulf Coast has a distinct advantage compared with many other parts of the country. Because the coast is actually an estuary and is "low energy," it is possible to use bioengineering to preserve the beach either in the absence of renourishment or with a minimum of renourishment projects. This gives the residents of the coast options that many other regions do not have. The natural model for this alternate approach is visible on the barrier islands.

The vegetation of the barrier islands holds the islands together. Their resilience in the face of a hostile environment and the high-energy events characteristic of the coast is truly impressive. Often overlooked is that their resilience is in the absence of human intervention. When a storm damages a section of a barrier island, in general (with the exception of certain salt marshes) the recolonization with native plants must occur slowly through seed and rhizome growth. If this model is applied to the 42-kilometer beach, the process of replanting the areas that lose their bioengineered protection could be done much more quickly than occurs on the barrier islands. The techniques described in this bulletin lead to growth and survival rates greatly in excess of those in natural systems. With this in mind, one would expect that bioengineered "soft protection" of the beach would be even more effective than that which occurs naturally.

Experiences at the Miramar and Schooner Pier experimental sites suggest that residents of the coast may well accept and appreciate the beauty of the "natural" beach. Comments from visitors and local residents have been almost unanimously supportive. Residents near the Miramar site visited with project personnel onsite and sent photographs and email messages. The general sense appeared to be that the work was significant and the site attractive and interesting. The Schooner Pier site is considered quite attractive. Once residents become fully aware that the native plants also serve a valuable function — the protection of the shoreline — it seems likely that their appreciation will only increase.

Ultimately, it is the residents of the 42-kilometer coast who will decide how the beach will be managed. It should be pointed out, however, that it is desirable to start the process of beach protection using native plants as soon as possible. The sooner the process begins, the greater will be the degree of protection, as well as the expertise and experience of those appointed to manage it. If residents prefer to continue with present management practices, this bioengineering option will still (depending upon the rate of deterioration) remain available. The time frame for effective bio-armoring is approximately 5 years.

In having this option, the residents of Biloxi, Gulfport, Long Beach, and Pass Christian may be luckier than their counterparts in other communities. Using bioengineering to soft armor the high-energy beaches of the Atlantic, Pacific, and parts of the Gulf coasts is not possible. As renourishment monies decrease, residents in these areas will have to build massive hard-armoring structures or will have to retreat from the coast. Effectively protecting low-energy areas such as the 42-kilometer beach using bioengineering is not only possible along the Mississippi Gulf Coast, it may be the most desirable method to do so.

Implementing this Approach on the Mississippi Gulf Shore

Native beach plantings will add to the visual variety of the beach aesthetics, and they will help to hold sand in place. The use of native plantings has to be combined with low-impact landscape management to allow for the growth of volunteer native plant grasses and forbs to compliment the planting of dominant dune creation species.

Planting designs should be based on beach use in particular areas. Determine the level of use and the influences of adjacent development, as well as access by automobile to the beach. Use these variables to determine the extent of landscape development. For areas of low use, create a natural beach landscape. Include emergent grass plantings with *Spartina alterniflora* along the edge and *Spartina patens* above the mean high-tide line. Marsh elder shrub can be planted individually at the back side of the *S. patens* grasses. There will be a zone with few plants above the *S. patens*. Beyond this open beach zone, lay out dune locations and plant *Uniola paniculata* in curvilinear lines to create the wind and wave barrier that will slowly build the dune. Place shrubs and trees within the layout of the dunes with trees located toward the top of the upper-beach landscape. This beach landscape will appear natural, will provide the framework for native volunteer plants to establish, will hold sand together, and will grow a beach that will become higher and may avoid becoming narrower. Landscape maintenance on this natural beach should be limited to hand pick-up of litter in order to allow for volunteer establishment of native plants that will help hold the sand together and stabilize the sand beach.

For intermediate and high-use areas on the beach, you can plant from the various components of the low-use beach that will compliment the use levels and activities. However, without a significant dune system with grasses, shrubs, and trees in the upper beach, wind-blown sand erosion will be significant and sand will be blown beyond the beach onto the adjacent roadway. Even in areas of high use, a significant sand-dune system should be implemented for wind-blown sand erosion control. Dunes with native plantings will be attractive and add to the ambience of the beach environment. Elimination of the emergent grasses and the *Spartina patens* will allow for open water. The trade-off is there will be more beach erosion without the lower beach grasses and shrubs. Landscape management on this beach can include either hand-raking of the beach zone or mechanical sifting of the sand. However, mechanical sifting compacts the sand and encourages water runoff and erosion of the top-sifted layer of sand. Hand-raking of man-made, washed-up debris would have a less adverse impact to the beach.

The Future of the Beach and the Importance of Making Difficult Decisions

There are two options for managing the beach landscape. One is to manage it with mechanical equipment to keep it flat and free of all natural and man-made materials except for sand. The other alternative is to manage it in concert with natural processes. The first option is the way the beach has been managed since the 1950s, and it has washed away four times during that time period. Working with the natural processes will create a beach that will persist. It will change appearance as it responds to the different cycles of nature, but it will always be a beach and look like a beach. In the natural sand-sharing system, sand is washed up daily by prevailing winds and waves. This sand dries out and is blown upbeach to add to the sand reserves. Seasonal storms add large quantities of sand, and this can help to grow the beach as well. Native beach plants help to hold the sand and create a larger and stronger beach that can repel some of the energy in storm surges. Sometimes all of the plants appear so damaged by storms that they look dead. But, the plants that are supposed to grow on the beach will usually come back.

Working with nature requires regular human thought and evaluation. There are times and places a beach might need additional plants to provide the best appearance and the ability to hold sand together. People should become aware of these forces and cycles of nature and work with them to create an outstanding beach landscape that is pleasing to the eye, will persist, and will offer the greatest protection to the mainland.

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Appendix I

Calculations Used in the Wind Erosion Example

Planted beach:

$l = 54*0.005*0.5/3.72 = 0.036$

where there are 18 plants with three stems each, stem diameter = 0.005 m, stem height = 0.5 m, and plot area = 3.72 m^2.

$\log_{10}(z_o /0.5) = 1.33 \text{ Log}_{10} (0.036) – 0.03 = -1.95$
$z_o = 0.5 * 10^{-1.95} = 0.0056$ m

Unplanted (i.e., sparsely planted) beach:

$l = 1*0.005*0.5/3.72 = 6.7x10^{-4}$.

where there is one plant with one stem, stem diameter = 0.005 m, stem height = 0.5 m, and plot area = 3.72 m^2.

$\log_{10}(z_o /0.5) = 1.33 \text{ Log}_{10} (6.7x10^{-4}) – 0.03 = -4.25$
$z_o = 0.5 * 10^{-4.25} = 2.8 \text{ x}10^{-5}$ m

Matlab program used to create Figure 11.

```
clear, clc
us = 20; %cm/s
n_p = 54;
n_u = 1;
A = 3.72;
d = 0.005;
h = 0.5;
lamda_p = n_p*d*h/A;
lamda_u = n_u*d*h/A;
lg_p = 1.33*log10(lamda_p) - 0.03;
lg_u = 1.33*log10(lamda_u) - 0.03;
zo_p = h*10^lg_p
zo_u = h*10^lg_u
for i = 1:5000
 z(i) = i/100;
 u_p(i) = (us/0.4)*log(z(i)/zo_p);
 u_u(i) = (us/0.4)*log(z(i)/zo_u);
end
semilogx(z,u_p*3600/(1000*100),'—',z,u_u*3600/(1000*100))
legend(' Planted', 'Unplanted')
xlabel('Elevation (cm)')
ylabel('Wind Velocity (km/h)')
```

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