ENDANGERED SEA TURTLE NESTING ACTIVITY ON UPPER TEXAS COAST BEACHES

Final Report to the

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ABSTRACT

Destruction wrought by Hurricane Ike to Galveston Island beaches as well as adjacent counterparts on Bolivar Peninsula and Follett's Island/Surfside severely altered the physical terrain on which sea turtle nesting has occurred on the upper Texas coast. Physical changes to the beach habitat likely destroyed those stretches that, under pre-Ike conditions, exhibited high sea turtle nesting potential. These changes also rendered most remaining beach terrain a candidate for much needed improvement as it related to increased nesting potential. The only component that the management guide required by the CMP Cycle #13 grant awarded to Texas A&M University at Galveston could identify were beach stretches lost to nesting because of natural phenomena, in this case, a hurricane named Ike. Nesting data for the aforementioned beaches during 2009, when compared to those recorded in 2008, indicate that most constituents were lost as candidates with nesting potential because of physical destruction resulting from Hurricane Ike. As such, the guide mandated by Task 5 of the aforementioned CMP Cycle #13 grant is essentially a requirement that, under current UTC beach conditions, is impossible to meet and of little value to the reader at this time.

A more timely reporting need with which to guide restoration and management of beach habitat along the UTC is the characterization of the post-Ike recovery of this habitat, especially as it relates to enabling sea turtle nesting activity to return to pre-Ike conditions. As such, TAMUG has chosen to meet final report requirements to its CMP Cycle #13 grant by summarizing beach habitat recovery initiatives and the current status of conditions resulting from these initiatives that nesting turtles might find when attempting to nest on the UTC in 2010 and beyond.

INTRODUCTION

Assessing the fate of ongoing and future recovery efforts within Texas' coastal ecosystems ravaged by Hurricane Ike in 2008 is vital to growing the State's economy, maintaining the integrity of constituent habitats, protecting coastal communities, and ensuring public access to and their wise use of these ecosystems. One high priority assessment is that related to recovery of upper Texas coast (UTC; defined as Sabine Pass to Matagorda Peninsula) beach ecosystems, given their economic and ecological importance and the massive destruction delivered by Hurricane Ike. This assessment is especially applicable to the Texas General Land Office's (GLO) Coastal Management Program research priorities dealing with Hurricane Ike's aftermath and overall coastal resiliency, with particular focus on ecosystem recovery rates and effectiveness of various beach restoration methods. These research priorities are especially pertinent to beaches from Surfside to Sabine Pass that experienced a 40-90 m landward retreat of their shorelines, a 1+ m loss in vertical sand depth, and virtual disappearance of constituent dune habitat so vital to the protection of UTC businesses and homes behind them as well as enriching coastal tourism options. Beaches such as these are vital components of coastal ecosystems that function as nesting grounds for sea turtles and a myriad of shorebirds and for which the Texas Coastal Management Program (CMP) has assigned priority issues in its efforts to ensure the long-term environmental and economic health of the Texas coast through management of the state's coastal natural resource areas. This is particularly true for the critically endangered Kemp's ridley sea turtle (*Lepidochelys kempii*), the species found nesting on Texas beaches in record numbers and whose ongoing population recovery is tied to maintaining the integrity of nesting beach habitat.

Recovery criteria in the Draft Bi-National Recovery Plan for the Kemp's Ridley Sea Turtle: Second Revision (NMFS and USFWS, out for public review and comment) and reinforced as recommendations by the current recovery plan (USFWS and NMFS, 1992) and Turtle Expert Working Group (TEWG, 2000) mandate long-term habitat protection and monitoring of nesting beaches in Mexico and Texas. The Draft Recovery Plan's highest priority need for Kemp's ridley recovery is to maintain and reinforce habitat protection efforts on nesting beaches, protect nesting females and maintain hatchling production levels. This recovery strategy aims to protect a species whose nesting population by 1985 had declined to 1% of its 1947 abundance (estimated at 40,000 nesting females in a single day!) as a result of poaching at its only nesting beach, Rancho Nuevo, Tamaulipas, Mexico, and incidental capture and drowning in the Gulf shrimp fishery (Magnuson et al., 1990; TEWG, 2000). Protection of the Rancho Nuevo nesting beach and implementation of turtle excluder devices (TEDs) into the shrimp fishery have facilitated, since the mid-1980's, a 14-16% increase in ridley nests laid at Rancho Nuevo (Heppell et al., 2005; NMFS and USFWS, unpubl.). The 20,290 ridley nests laid at Rancho Nuevo in 2009 represent an estimated 8,116 females (Jaime Pena, Gladys Porter Zoo, Brownsville, TX, per. comm.). Although the Rancho Nuevo nesting beach receives the majority of attention in the Draft Recovery Plan for implementing recovery strategies, a primary criterion for downlisting ridleys from endangered to threatened status is to ensure long-term protection of nesting beaches in Texas (NMFS and USWFS, unpubl.). Protection of Texas beaches is critical in attaining the plan's goal of long-term, bi-national effort to reestablish nesting to form a secondary nesting colony that supplements nest production at Rancho Nuevo as well as provides surrogate nesting potential in the case that nesting habitat is impaired by tropical events or anthropogenic causes.

The April 1, 2009 start of the sea turtle nesting season in Texas mandated that recovery of UTC beach ecosystems also received elevated priority due to fear of what upper coast beaches ravaged by Hurricane Ike offered egg-laden Kemp's ridley females looking for suitable dune habitat in which to dig their nests. This mandate was heightened by the increasing importance of beaches from Bolivar Peninsula to South Padre Island as critical Kemp's ridley nesting habitat through 2008. State-wide nesting totals seemed to lessen concern for hurricane-related impact to nesting activity, especially given the fact that Kemp's ridley nesting activity in Texas continued to increase annually since 2002, with 197 nests laid in 2009 surpassing the 2008 record of 195.

Although most nesting activity in Texas occurs on Padre Island National Seashore (PINS) and South Padre Island (65% in 2008; 84% in 2009), upper coast beaches were increasingly important contributors to the State's nest totals prior to Hurricane Ike. Like that for all State beaches, the UTC, with 17 documented nests, exhibited record nesting activity in 2008 (Table 1). Sixteen Kemp's ridleys and one loggerhead nested from Bolivar Peninsula to Quintana Beach in Surfside. Yearly increases in ridley nesting on the UTC have coincided with population recovery trends at Rancho Nuevo and suggest a northern extension of this species' nesting range onto the UTC or a reestablishment of historical nesting grounds there (Seney and Landry, 2008). Just as important is the growing role UTC beaches play as a satellite nesting ground that provides a population recovery option in the event Rancho Nuevo beaches are destroyed by a hurricane or insult such as an oil spill.

Until 2008, beaches from High Island to Surfside led the upper Texas coast in sea turtle nesting activity, especially that contributed by the Kemp's ridley (Table 1). Passage of Hurricane Ike in September 2008 and the destruction it wrought on the aforementioned beaches appeared to change this trend. Of the 16 ridley nests documented across the entire upper Texas coast during 2009 (Table 1), 9 were laid on beaches south of Surfside and included the following totals: Quintana Beach – 2; Bryan Beach – 2; Brazoria County (north of Sargent) – 1; Sargent Beach – 1; and Matagorda Peninsula – 3. Bolivar Peninsula beaches, the co-leader (with Galveston Island) in sea turtle nests with 6 during 2008, produced only 1 nest in 2009. Galveston Island, the other 2008 co-leader, produced only 3 nests in 2009. In addition, four aborted nesting crawls documented on UTC beaches in 2009 were likely due to nesters failing to find suitable nesting conditions. These temporal and spatial differences in nesting activity along the upper Texas coast could be attributed to two possible causes. The first and most likely of these causes is the destruction to beaches from Surfside to High Island, most of which were in the direct path of Hurricane Ike or east of the line of its passage and on the "dirty" or most destructive side. The second possible cause is the initiation and/or increase in the conduct of formal sea turtle nesting patrols on beaches south of Surfside during 2009.

Excitement over the aforementioned Texas nesting trends and their contribution to ridley population growth has been tempered by Ike's passage and the prospect that the UTC has lost considerable momentum in helping to achieve the Recovery Plan's goal that constituent beaches support a secondary nesting colony. The prospect for such a loss is strengthened by this author's comparison of pre- and post-Ike conditions on UTC beaches. Post-Ike, on-site inspections of the aforementioned 17 nesting locations on Bolivar, Galveston and Surfside beaches in 2008, enabled by GPS coordinate data of these locations recorded during the anthor's daily nesting patrols and random response to nesting events, indicate Ike leveled dunes where sea turtles laid their eggs and flattened the vertical landscape that enables a female to locate suitable nest sites (Figs. 1-6). Natural beach slope, typically between 3 and 5%, has been flattened to 1% [Robert Webster, coastal geologist in TAMUG's Laboratory for Oceanographic and Environmental Research (LOER), per. comm.], leaving Bolivar Peninsula beaches with standing water over historical nesting sites after high tide and rain events (Fig. 7). These areas, if left in their present slope, will likely deter females from nesting and, if nesting did occur, their eggs would drown. Washed from beaches are acres of sand whose chemical and physical qualities are essential to a female digging a nest, incubating her eggs, possibly locating the same beach when returning to nest in 2 to 3 years, and imprinting hatchlings with similar natal beach location information.

Case studies of impact from hurricane events and various beach renourishment efforts on sea turtle nesting dynamics mandate that Hurricane Ike's aftermath and efficacy of subsequent recovery initiatives in restoring nesting habitat are factors that must be evaluated if the UTC is to continue to develop as a secondary ridley nesting colony supporting that at Rancho Nuevo. Of particular concern are findings by Hillis et al. (1990) and Hillis and Phillips (1995) that passage of Hurricanes Hugo and Marilyn across nesting beaches at Buck Island Reef, St. Croix, US Virgin Islands caused nesting activity to shift to atypical nesting habitats while false crawl ratio increased from 31 to 59% post-storm event. Crain et al. (1995) and Rumbold et al. (2001) found increased sand compaction by beach nourishment activities caused nesting success to decrease the first season following nourishment. The latter study also reported increased false crawls by loggerheads the first post-nourishment season. Green (2002) summarized other studies evaluating impact of beach nourishment and reported that constituent habitat remained unsuitable for nesting for 2 to 3 years and, in some cases, 7 years post-nourishment.

RESEARCH OBJECTIVES

Final report requirements as outlined in Task 5 of the CMP Cycle #13 grant to TAMUG entitled "Endangered Sea Turtle Nesting Activity on Upper Texas Coast Beaches" call for the development of a "Guide to Managing Sea Turtle Nesting Habitat on the Upper Texas Coast." Specifically, TAMUG was to develop a working guide to sea turtle nesting on West Galveston Island beaches and their inter- and postnesting movements during 2009. This guide was to identify those beach stretches: 1) with highest sea turtle nesting potential; 2) whose nesting potential should be improved; and 3) lost to nesting because natural phenomena (i.e., erosion) or man-made alterations (i.e., Geo-tubes) have rendered them unattractive to nesting or pose a threat to survival of the nest and its contents.

Destruction wrought by Hurricane Ike to Galveston Island beaches as well as adjacent counterparts on Bolivar Peninsula and Follett's Island/Surfside severely altered the physical terrain for which the aforementioned guide was to be developed. Physical changes to the beach habitat described earlier in this report likely destroyed those stretches that, under pre-Ike conditions, exhibited high nesting potential. These changes also rendered most remaining beach terrain a candidate for much needed improvement as it related to increased nesting potential. The only component that the mandated guide could identify were beach stretches lost to nesting because of natural phenomena, in this case, a hurricane named Ike. Nesting data for the aforementioned beaches during 2009 (Table 1), when compared to those recorded in 2008, indicate that most constituents were lost as candidates with nesting potential because of physical destruction resulting from Hurricane Ike. As such, the guide mandated by Task 5 is essentially a requirement that, under current UTC beach conditions, is impossible to meet and of little value to the reader at this time.

A more timely reporting need with which to guide restoration and management of beach habitat along the UTC is the characterization of the post-Ike recovery of this habitat, especially as it relates to enabling sea turtle nesting activity to return to pre-Ike conditions. As such, TAMUG has chosen to meet final report requirements to its CMP Cycle #13 grant by summarizing beach habitat recovery initiatives and the current status of conditions resulting from these initiatives that nesting turtles might find when attempting to nest on the UTC. Results summarized herein concentrate primarily on describing the physical state of UTC beaches prior to the 2010 sea turtle nesting season, a 3.5 month long period in which nesting females should provide "biological" insight into the integrity of constituent habitats. While coverage of all relevant environmental factors and human activities influencing the integrity of beach ecosystems and sea turtle nesting habitat on upper Texas coast beaches is beyond the scope of this paper, those identified as critically important (beach nourishment, beach slope and width, vegetation coverage, among others) are summarized below.

RESULTS AND DISCUSSION

Post-Ike Recovery of UTC Beaches, A Broad View: Highly dynamic nesting beach environments such as those along the upper Texas coast continually erode and accrete in response to wind, waves, currents, storms, and alterations in sea level (Lebuff and Haverfield, 1992; Peterson and Bishop, 2005). Although sea turtles often exhibit strong nest site fidelity to natal beaches (Meylan et al., 1990; Bjorndal, 1995; Shaver, 2005), a multitude of environmental factors may significantly impact the attractiveness of a specific beach to nesters (Santos et al., 2006) and the "seafinding" ability of hatchlings emerging from nests (Salmon et al., 1995; Bertolotti and Salmon, 2005). As such, physical conditions of UTC beaches as it relates to their attraction to sea turtles will be the primary thrust of this recovery assessment.

Ongoing restoration of UTC beaches from High Island to the Surfside Jetty to pre-Ike conditions is slow and varies across coastal communities and constituent beaches, largely due to the Texas General Land Office's (GLO) prohibiting return of sand washed onto interior portions of the coastal zone to nearby beaches. Post-Ike conditions on these beaches exhibit various levels of physical and chemical impairment, ranging from the severely impacted Bolivar Peninsula ravaged by Ike's "dirty side" and a 6+ m high storm surge to those of Brazoria County beaches north of and including Surfside where the hurricane's "clean side" delivered somewhat less impact and habitat recovery may occur quicker. Bolivar beaches represent the worst case scenario in regard to Ike's impact and recovery potential, given their receiving the brunt of storm surge, as well as the loss of 3600 homes and businesses on the peninsula greatly decreases the number of entities actively attempting to restore beach habitat that protected their structures before Ike's passage. Galveston Island affords presence of accreting beaches on East Beach and near San Luis Pass, armored counterparts along its Seawall that have recently been renourished, as well as west end constituents where Ike's impact, although seemingly less than that at Bolivar, is the subject of various beach restoration efforts adjacent to a multitude of beach homes, whose owners far exceed their Bolivar Peninsula counterparts, in terms of both number and beach restoration potential. Beaches from San Luis Pass to Surfside are, for the most part, undeveloped until one reaches corporation limits of the Village of Surfside. Although pre-Ike conditions on these beaches exhibited considerable erosion, their dunes were generally as good as those of counterparts on Bolivar Peninsula and Galveston Island. Visual surveys of these beaches by the author during the 2009 nesting patrols indicate that Ike's physical impact to them was less than that at Bolivar Peninsula.

Beach Width & Slope: Two very visible beach-related results from the impact of Hurricane Ike are: 1) wide beaches in areas where erosion was not a problem before the storm's passage; and 2) narrow beaches where erosion and/or erosion control devices were the pre-storm norm (Figs. 8 and 9). Alterations in beach width and slope can arise from multiple anthropogenic activities, including shoreline development, beach nourishment, vehicular traffic (Santos et al., 2006; Fish et al., 2008), and installation of erosion control structures (Lebuff and Haverfield, 1992; Feagin et al., 2005). Female nest site selection and subsequent reproductive success are partially determined by the inverse correlation between beach width and slope that, in conjunction with tidal amplitude, regulate the potential for inundation-related embryonic mortality and hatchling survival on land (Whitmore and Dutton, 1985; Marquez-M., 1994; Garmestani et al., 2000). Nests laid below the high tide line typically experience lower hatching and emergence rates or complete embryonic mortality, as increased salinity associated with seawater wash over of nests can disrupt egg metabolic processes and/or asphyxiate developing embryos (Whitmore and Dutton, 1985). Inadequately sloped beaches increase the crawl distance necessary for females to access elevated sites less vulnerable to tidal inundation (Horrocks and Scott, 1991; Santos et al., 2006) and the susceptibility of incubating nests to flooding (Marquez-M., 1994). Hatchlings emerging from nests located high on overly wide beaches of reduced slope expend more energy to reach the sea, thus increasing exposure time to land-based predators (Horrocks and Scott, 1991; Marquez-M., 1994; Mrosovsky, 2006). Narrow eroded or steeply sloped beaches may visually deter nesters and decrease overall nesting frequency (Garmestani et al., 2000; Montague, 2008); such is the case for females required to expend increased energy to reach preferred nesting sites on beaches with significant inclines (Santos et al., 2006). Nests deposited on narrow beaches whose width is constrained by development are expesed to negative impacts associated with infrastructure as well as increased risk of seawater saturation (Fish et al., 2008).

Although beach profile preference varies among sea turtle species (Mrosovsky, 2006) and remains undetermined for Kemp's ridleys, the moderate profile characteristics of Rancho Nuevo's beach may be considered ideal for ridley females, nests, and nest products. Nests incubating on beaches of moderate slope may benefit from improved substrate drainage and proper humidity levels (Marquez-M., 1994). Moderately sloped beaches that provide a multitude of nest placement options at varying distances above the high tide line are advantageous to nesting success as spatially-distributed nests tend to mitigate negative impacts associated with dynamic beach environments affected by stochastic events (Mrosovsky, 2006). In certain years, substantial land-based predator pressure may select for nests laid close to the surf, while nests located high on the beach may produce more hatchlings during seasons with unusually strong storms. Robust estimates of preferred nest locations along the horizontal beach gradient from forebeach to second foredune do not exist for Kemp's ridleys nesting on the upper Texas coast. Although ridley nests in Texas have been laid at all positions along the horizontal beach slope, all but one nest documented at hatching through 2009 have been located high on the beach protected from tides (Shaver, 2008; Landry and Hughes, unpublished data), indicating that sufficiently-wide beaches free of tidal inundation are crucial for ridley nesting success in Texas

Beach Nourishment: Crain et al. (1995) reported that renourishment/restoration produces a beach that is often different in several ways from that of its natural counterpart, including 1) being harder; 2) retaining more water; and 3) sorting of constituent sand in different ways because they are not constructed (i.e., reconstructed) in the same way as are natural beaches. These differences represent an acute concern in evaluating post-Ike recovery and integrity of beach ecosystems as well as how they function to facilitate sea turtle nesting activity, with this latter parameter a biological indicator of pre-Ike integrity. Loss of sand and dunes, change in beach slope and width because of this loss, when combined with the aforementioned and disparate ways in which beaches are being renourished across Bolivar Peninsula, Galveston Island and Surfside, are a current concern. Furthermore, efforts to restore the natural elevation gradient of these beaches and original integrity of dune habitats are in various stages. Galveston beaches along the Seawall have been renourished with sand trucked from East and Stewart Beaches (one of few accreting UTC beaches) as well as dredge material from the Gulf floor. Escarpments that can block turtles from reaching nesting areas (Davis et al., 1993, among others) and result in increased non-nesting emergences (Ehrhart et al., 1994, among others) have remained for months after Seawall beaches were nourished. Renourishment efforts on Bolivar Peninsula and west Galveston Island primarily involve redistributing sand remaining on beaches by county and municipal entities. One of the first and very visible renourishment initiatives associated with redistribution of sand washed on to Highway 87 on Bolivar Peninsula and Highway 3007 on West Galveston Island was the trucking of this sand to adjacent beaches where it was placed in large mounds for eventual screening of hurricane-strewn debris (Fig. 10). Screened sand was then trucked by heavy equipment to other areas of the beach (Figs. 11). These renourishment efforts involved heavy equipment that compacted sand on constituent beaches (Fig. 12), thus increasing the risk that they may be unsuitable for a nester to dig a nest and lack adequate gas exchange and humidity levels needed for egg incubation (several citations summarized in Crain et al., 1995 and Green, 2002). The redistribution of screened sand appeared random in many beach areas and did not seem to include protocols to reestablish the beach to its original slope and width. This latter concern was addressed in the Beach Width and Slope section in this report.

Other efforts include individual homeowners and subdivision associations ignoring GLO's prohibition by paying private contractors to recapture sand from their lawns and adjacent streets (Fig. 13) as well as truck in other non-sandy soils for placement on beaches, where it is typically put upland of its pre-Ike dune location. Loss of sand and GLO restrictions on its recovery have caused UTC home- and subdivision owners to use non-sandy sources (Fig. 14) that may increase the risk this replacement substrate does not exhibit the same physical and chemical characteristics of that washed away, thus rendering nest building and egg incubation problematic (Yanno and Slutzman, 1992). In addition, various "sand-catching" initiatives, including recycled Christmas trees tethered together in rows parallel to the beach as well as large, hay bales stacked against one another in similar rows (Figs. 15 and 16), designed to expedite the development of dunes are being deployed by homeowners on both Bolivar Peninsula and West Galveston Island. Many of these sand-catching initiatives have been in place on the aforementioned beaches with little evidence that measurable quantities of sand, much less actual dunes, have materialized.

Addition of fill material to elevate and extend beaches seaward in developed coastal zones prone to erosion and flooding is a common non-permanent engineering solution (Lebuff and Haverfield, 1992; Crain et al., 1995) employed to stabilize shorelines (Peterson and Bishop, 2005), protect property, and increase available recreational area (Rumbold et al., 2001). While beach nourishment significantly reduces altered sediment transport and downdrift erosion associated with hardened structures like seawalls and groins (Lebuff and Haverfield, 1992; Feagin et al., 2005), it is not ecologically benign (Peterson and Bishop, 2005; Montague, 2008). Ecological impacts of beach nourishment remain uncertain despite four decades of agency-mandated monitoring (Peterson and Bishop, 2005; Montague, 2008). Monitoring studies typically lack standardization and scientific rigor, while research conclusions are flawed by inadequate evidence, data analysis or misinterpretation (Peterson and Bishop, 2005). Nonetheless, available data indicate sediments obtained from offsite sources, including ship channels and offshore borrow pits, may adversely affect sea turtle nesting success. Such sediments may alter a beach's slope; sand density, color, mineral content, and grain size; shear resistance; and moisture content (Nelson and Dickerson, 1988; Benedet et al., 2004; Chen et al., 2007) due to compositional differences in the proportion of carbonate sand, quartz sand, shell, coral, clay, and silt (Crain et al., 1995).

Benefits inherent in augmenting available nesting habitat through renourishment efforts (Lebuff and Haverfield, 1992; Crain et al., 1995; Montague, 2008) may be offset by degradation and disturbance of beach and nearshore environments (Peterson and Bishop, 2005), alteration of beach profiles (Brock et al., 2008) and constituent substrates' natural physical and chemical properties, and formation of beaches unsuitable for nesting females and/or clutch incubation (Crain et al., 1995). Effects of physical and chemical substrate permutations on a nester's short- and long-term nest site fidelity are poorly understood (Crain et al., 1995). Related research has documented substantial increases in frequency of non-nesting emergences correlated with significant reductions in reproductive output from both loggerhead (Rumbold et al., 2001) and green sea turtles (Brock et al., 2008), particularly during the first season post-nourishment. Nourishment-induced changes in female nest site selection and digging behavior may deleteriously affect offspring survival and future reproductive contribution as nest success is, to a certain extent, dependent upon nest cavity configuration and the hydric and thermal environment of the substrate (Crain et al., 1995). Inappropriate incubation temperatures caused by alterations in sand color can negatively affect embryo development, and variations in substrate water potential can limit diffusion of water, nutrients or oxygen across the semi-permeable eggshell (Crain et al., 1995). In addition, sand compaction resulting from nourishment activities or alterations in substrate shear resistance can physically impede or prevent female nest excavation or hatchling emergence (Marquez-M., 1994; Crain et al., 1995; Chen et al., 2007), thus diminishing reproductive success.

Scoured Beach Habitat: Scouring of beaches by Hurricane Ike along with the likelihood that beach renourishment/restoration efforts typically leave constituent substrates much harder (as reported by Crain et al. 1995) than those of pre-storm counterparts is a common sight on Bolivar Peninsula and West Galveston Island beaches (Figs. 17 and 18). Evidence of scouring action still remains on Bolivar Peninsula in the form of exposed Beaumont clay washed clean of several centimeters and/or meters of sand that covered it prior to Hurricane Ike. Heavy equipment used in transporting recovered sand to debris sieving locations on the beach and subsequent relocation of this sand to other beach sites also compounded the problem by compacting sand that was on the beach. These hard substrates render nest excavation by a nesting female literally impossible. False crawls noted during the 2009 nesting season were often the case on beach sections where Beaumont clay or hard, packed sand was found (Fig. 19).

Inundated Beach Habitat: Standing water was a common sight on UTC beaches after Hurricane Ike and a condition that remains from High Island to Follett's Island (Fig. 7). This condition typically exists in areas where dunes were located pre-Ike and has been compounded by beach compaction due to heavy equipment used in moving sand back on the beach and later redistributing it. Tracks of nesters attempting to nest on beaches where standing water existed were often very circuitous and longer than those left by counterparts who nested on these beaches during pre-Ike seasons (Fig. 20). This pattern suggests nesters, upon encountering standing water on the beach, undertook extra effort to avoid it and continued to search for a suitable nest site nearby or simply turned gulfward in an aborted nesting attempt.

Status of Sand Dunes: Presence and absence of sand dune development along the UTC varies from total lack of embryonic dunes on eroding beaches (and lack of effort on the part of a homeowner or subdivision; Fig. 21) to fairly well developed dunes on accreting beaches such as those near San Luis Pass (Fig. 22). Dunes that do exist on the UTC exhibit varying degrees of vegetative cover ranging from no emergent plants (Fig. 23) to complete coverage by emergent plants (Fig. 24). Vegetative cover on other dunes is often comprised of salt-sensitive species such as St. Augustine grass (Fig. 25) that will eventually die, thus leaving the dune with little supporting integrity. There are several well designed dune complexes on West Galveston Island that are covered by a variety of salt tolerant vegetation (Fig. 26).

The Texas Open Beaches Act § 61.011, by utilizing the existing vegetation line to differentiate between public beach and private property bordering the Texas Gulf coast, underscores the critical importance of dune plant communities in policy making and beach habitat management. Upper Texas coast species, including sea oats (*Uniola paniculata*), bitter panicum (*Panicum amarum*), seashore dropseed (*Sporobolus virginicus*), and marsh-hay cordgrass (*Spartina patens*), are essential components of healthy dunes that function as plant successional communities to build dunes, bind sediments, and reduce erosion (Marquez-M., 1994; Feagin et al., 2005). However, engineering solutions to coastal erosion (including seawalls and geotextile tubes), beachfront development, and non-native lawn vegetation have created landward barriers to inland dune migration, thereby confining dune plant communities to shrinking zones where characteristic successional patterns are disrupted (Feagin et al., 2005). Failure of embryonic dunes to form gulfward of human-erected barriers disrupts natural seed dispersal mechanisms and isolates plant communities, with both impacts resulting in loss of critical late-successional vegetation. It is this loss in vegetative cover that escalates beach erosion rates (Feagin et al., 2005).

Vegetative cover also is a critical component in sea turtle nest site selection and nesting success. Hawksbill turtle (*Eretmochelys imbricata*) nesting behavior is influenced by vegetative cover, with females displaying a significant preference for vegetated over non-vegetated sites (Horrocks and Scott, 1991) and predisposed to nesting along the beach perimeter adjacent to the vegetation line (Santos et al., 2006). Lower sediment compaction rates associated with vegetative cover and the ability of constituent rootlets to loosen substrate positively influence hawksbill nesting success, given the fact that hatchling emergence success is inversely correlated with compaction rate (Horrocks and Scott, 1991). This correlation may be a function of increased probability of hatchling suffocation and exhaustion associated with emergence attempts from nests deposited in more compacted substrates (Horrocks and Scott, 1991). The vegetation line is also a crucial component in green turtle (*Chelonia mydas*) nest site selection and subsequent reproductive success (Chen et al., 2007). Dune plant communities may function as nest placement indicators to females, as vegetated beaches minimize the risk of nest inundation and provide substrates with compaction values conducive to digging while maintaining nest cavity integrity without collapse (Chen et al., 2007). Although data relating nest site selection by Kemp's ridleys to vegetative cover are lacking, vegetated dunes are likely a critical visual determinant in this selection, as females preferentially nest adjacent to or on the foredune (Marquez-M., 1994).

Conversely, reproductive success may be lower for nests deposited in heavily vegetated areas. Chen et al. (2007) noted that females were deterred from excavating nests in locations where vegetation coverage exceeded 40%, as dense root systems reduced ease of digging. Embryonic mortality can be increased by root mats encompassing or perforating incubating eggs deposited in profusely vegetated areas (Whitmore and Dutton, 1985). Hatchlings emerging in dense vegetation are denied visual orientation cues for seafinding, resulting in disorientation or misorientation, particularly on moonless nights (Godfrey and Barreto, 1995). Thick dune plant communities can function to slow forward momentum and may entangle or entrap hatchlings, thus increasing predation and desiccation risks (Godfrey and Barreto, 1995). Despite these findings, maintenance and enhancement of dune plant communities are essential to maximize overall sea turtle reproductive success. Females require visual cues from, but typically avoid nesting in, heavily vegetated areas while dune plant communities provide hatchlings emerging from nests deposited lower on the beach with critical visual seafinding cues (Bourgeois et al., 2009).

Dune Building/Renourishment: Like those for vegetative cover, dune building/renourishment activities on the UTC exhibit a wide array of sand accreting protocols. One of these is the sand fence protocol of catching sand and protecting developing dunes. Although numerous sand fences have been erected on West Galveston Island, very few exhibit the angled orientation (Fig. 27) compatible with accreting sand as well as enabling nesters and hatchlings to move freely from beach to dune or dune to beach. Variations off this design are open fences oriented perpendicular to the dune line (Fig. 28), some of which are bordered by planted vegetation between the fence and intended dune line (Fig. 29). These variations in sand fence design and placement are novel and must be evaluated in their ability to build dunes in a sea turtle compatible manner. The majority of sand fencing seen on West Galveston Island is the "turtle unfriendly" design running in a continuous, parallel fashion without breaks that would allow free passage of nesters and hatchlings (Fig. 30).

Dune Crossover Designs: The majority of dune habitat in development on the UTC, especially that on West Galveston Island where this development exceeds that on Bolivar Peninsula and Follett's Island/Surfside beaches, is devoid of dune crossovers that safeguard the dune's integrity from foot and/or vehicular (golf carts) traffic (Fig. 23). Most dune crossovers present on these beaches are well designed and turtle friendly (Fig. 31). More of these crossovers must be erected to ensure the integrity of dune habitat.

CONCLUSIONS

Alterations in nest temperature, hydric environment and gas exchange, that may result from beach renourishment initiatives could affect hatching rates and possibly vigor and survivorship of hatchlings (Ackerman, 1980), mandate a thorough assessment of constituent beach characteristics from a pre- and post-Ike perspective for subsequent comparison with sea turtle nesting activity before and after Ike's passage. This comparison is particularly crucial given the fact that a nesting female's ability to select and excavate a suitable nest chamber as well as ensure a microclimate suitable for egg incubation is generated by interaction among the physical characteristics of the materials composing a beach, the physical structure of the beach, local climate and the eggs in the nest (Ackerman 1996). However, because hydric, thermal and respiratory properties of soil as well as the nester's ability to dig a nest are a function of soil wetness and compaction, it is anticipated that microclimate, topography and sediment characteristics of renourished/restored beaches may be different from those of natural counterparts.

Any recovery initiative occurring on UTC beaches must be evaluated over the long term as they relate to repairing environmental damage from Hurricane Ike and strengthening the resiliency required for healthy coastal ecosystems to function. To this end, assessing recovery rates of UTC beach ecosystems must involve physical and biological indicators to be meaningful. Furthermore, the rate at which this restoration occurs must be determined on the basis of the time required for a habitat to return to at least its pre-Ike integrity (= physical, chemical and biological) and regain its role(s) in contributing to ecosystem functions that include sea turtle nesting. Although habitat restoration is only as good as the habitat's ability to resume and/or improve its pre-storm function(s), current conditions will primarily allow only physical indications of beach habitat recovery to take place. Biological indications of beach recovery, particularly the degree to which dune habitats become attractive to and are used by sea turtles, will be difficult to assess until sufficient time has passed for these agents to return to pre-Ike status. Data presented in this report indicate that UTC beaches have not had sufficient time or attention to recover to pre-Ike conditions. While coverage of all relevant environmental factors and human activities influencing the integrity of beach ecosystems and sea turtle nesting habitat on upper Texas coast beaches is beyond the scope of this report, those identified as critically important (beach nourishment, beach slope and width, vegetation coverage) must be considered in the post-Ike recovery of UTC beaches.

ACKNOWLEDGEMENTS

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Year	Bolivar Peninsula	Galveston Island	Brazoria County (north of Surfside)	Surfside Beach	Quintana Beach	Bryan Beach	Brazoria County (north of Sargent)	Sargent Beach	Matagorda Peninsula	UTC Totals
2002		2				1			1	**4**
2003		1								**1**
2004	2	2		1						**5**
2005		7							1	**8**
2006		9		1						**10**
2007	1	7		2		1			4	**15**
2008	6	6	1	2	1					**16**
2009	1	3	3		2	2	1	1	3	**16**
Total # of Nests	**10**	**37**	**4**	**6**	**3**	**4**	**1**	**1**	**9**	**75**

Table 1. Kemp's ridley sea turtle nesting trends on the upper Texas coast during 2002 through 2009.

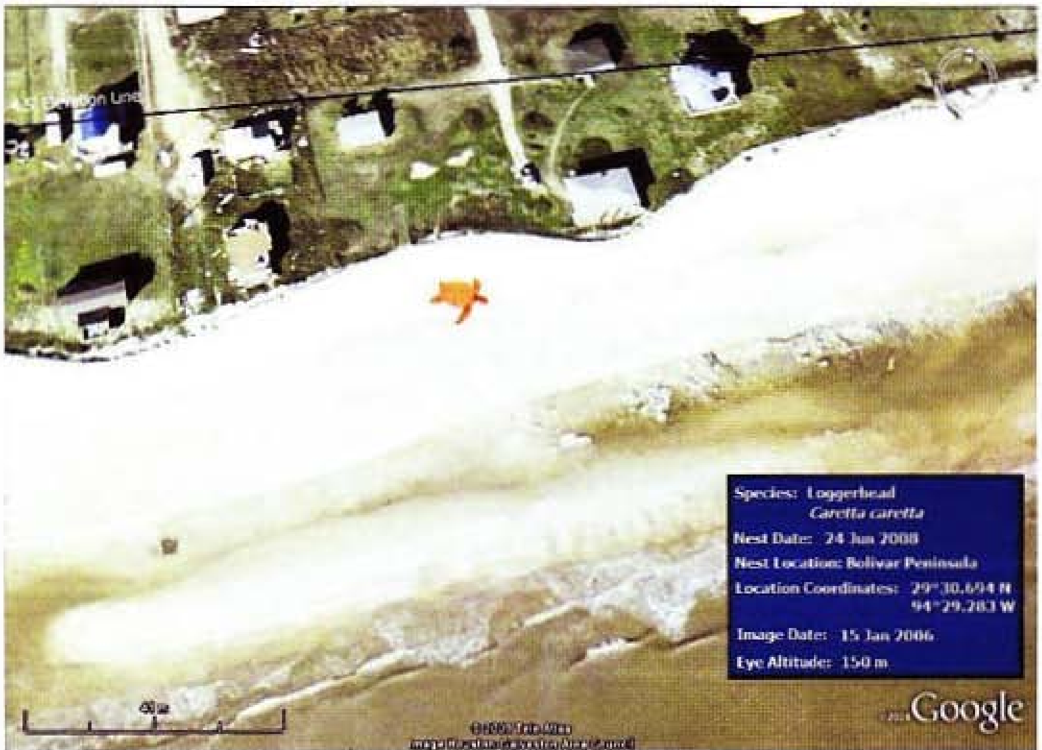

Figure 1. Pre-Hurricane Ike satellite photograph of a loggerhead sea turtle nest site laid on Bolivar Peninsula 24 June 2008. Turtle icon marks nest site.

Figure 2. Post-Hurricane Ike satellite photograph of a loggerhead sea turtle nest site laid on Bolivar Peninsula 24 June 2008. Turtle icon marks original nest site. Dark coloration of photograph is due to terrain being under water.

Figure 3. Pre-Hurricane Ike satellite photograph of a Kemp's ridley sea turtle nest site laid on West Galveston Island 30 May 2008. Turtle icon marks nest site.

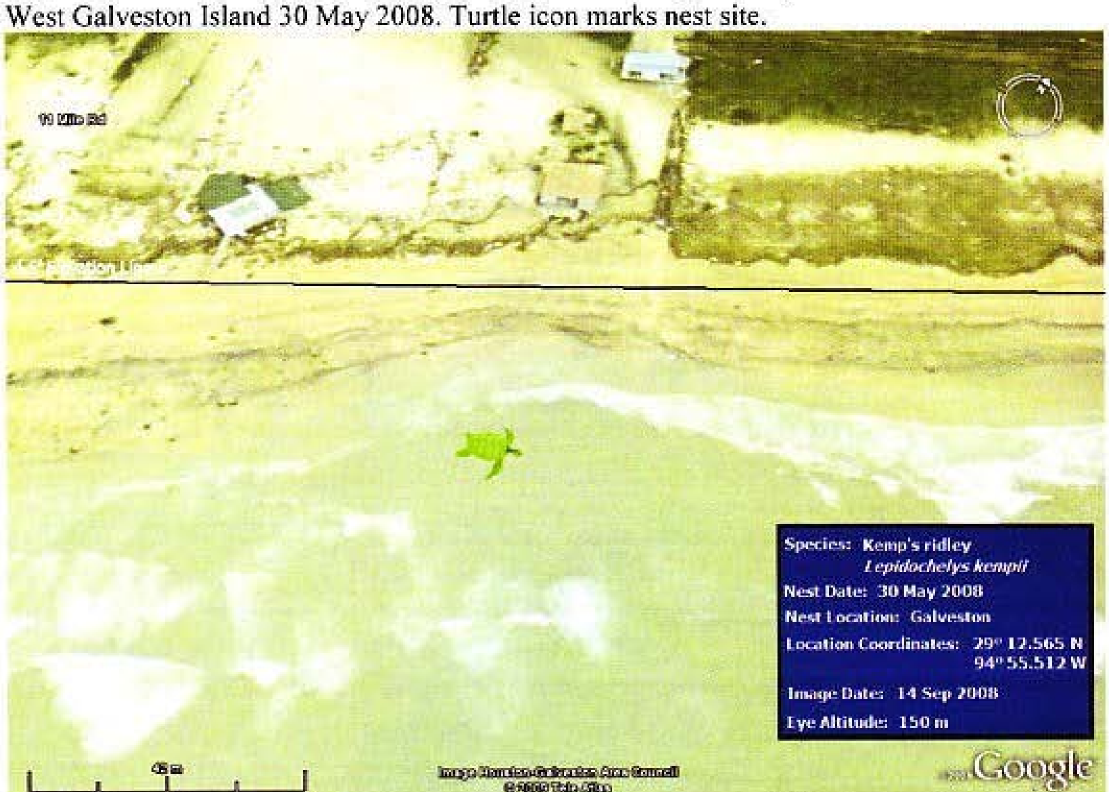

Figure 4. Post-Hurricane Ike satellite photograph of a Kemp's ridley sea turtle nest site laid on West Peninsula 30 May 2008. Turtle icon marks original nest site.

Figure 5. Pre-Hurricane Ike photograph of a Kemp's ridley nest site laid on Bolivar Peninsula May 30, 2008. Nest site is within dark oval.

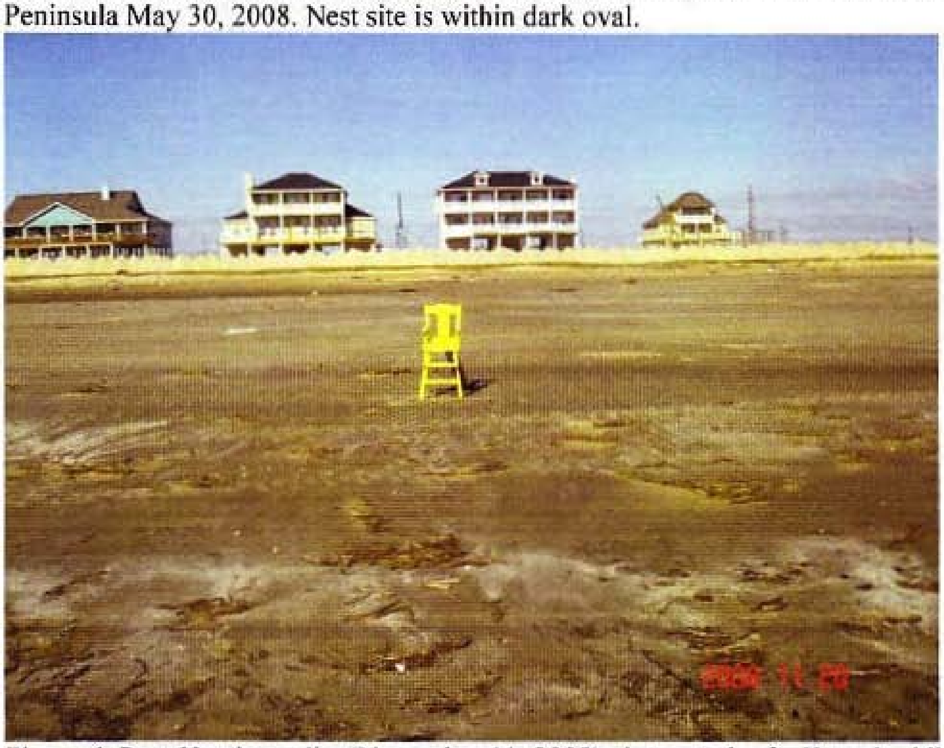

Figure 6. Post-Hurricane Ike (November 11, 2008) photograph of a Kemp's ridley nest site originally laid on Bolivar Peninsula May 30, 2008. Yellow chair marks original nest site.

Figure 7. Storm-scoured, low lying area with standing water on Bolivar Peninsula where Kemp's ridleys had nested prior to Hurricane Ike.

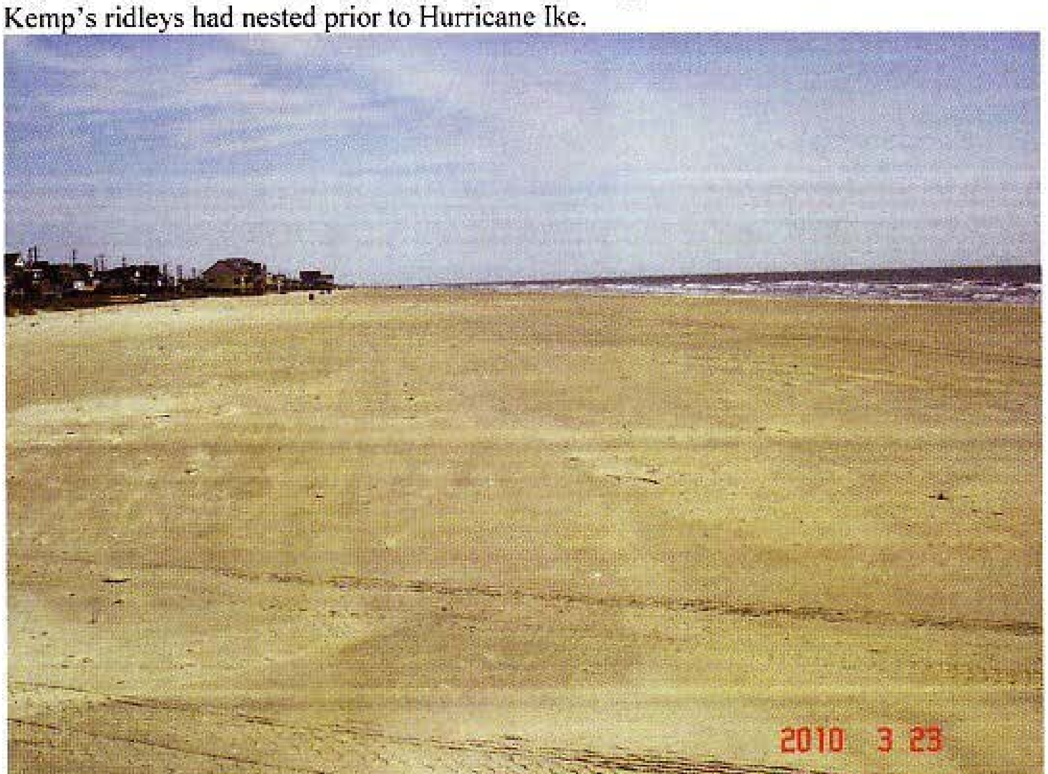

Figure 8. Post-Hurricane Ike photograph of wide, slope less beach on West Galveston Island.

Figure 9. Post-Hurricane Ike photograph of narrow, slope less beach on West Galveston Island.

Figure 10. Typical storm debris cleaning site and heavy equipment used to transport sand on Bolivar Peninsula.

Figure 11. Heavy equipment used to transport clean sand used in renourishing Bolivar Peninsula and Galveston Island beaches.

Figure 12. Bolivar Peninsula beach exhibiting highly compacted sand substrate as a result of heavy equipment used in renourishment activities.

Figure 13. Private contractors recovering sand from homeowners' yards in the rebuilding of dunes on Bolivar Peninsula.

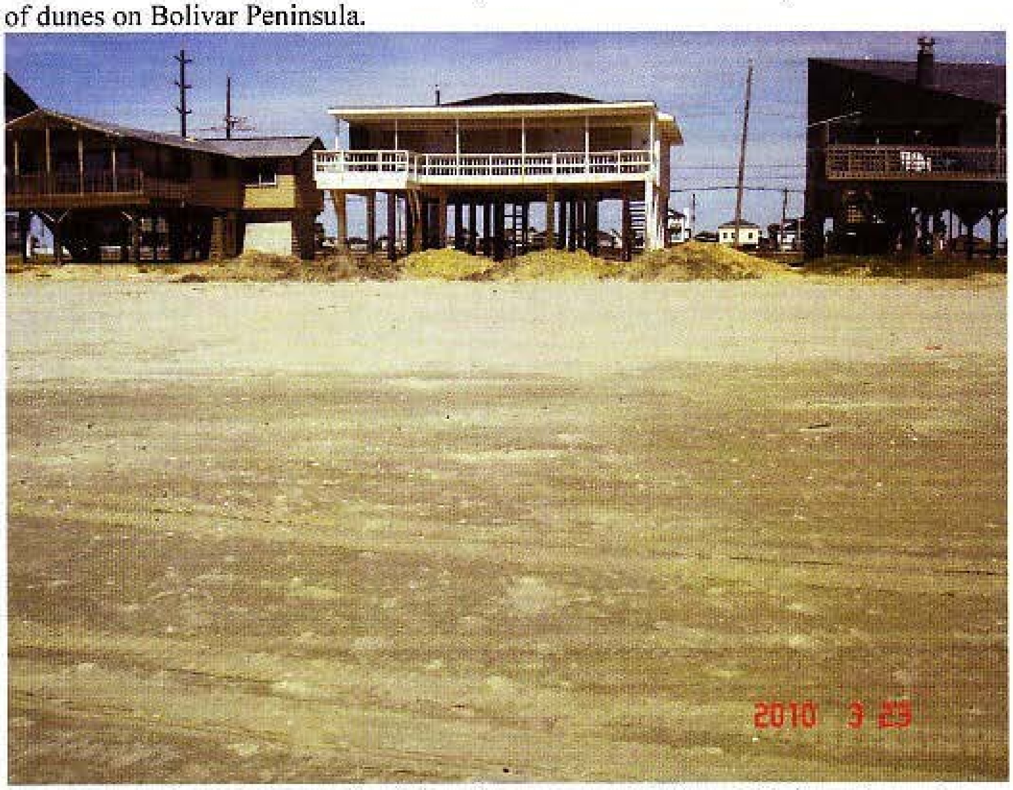

Figure 14. West Galveston Island site where non-sand substrate(s) is used as a dune renourishment initiative.

Figure 15. Tethered Christmas trees recycled on Bolivar Peninsula as a dune renourishment initiative.

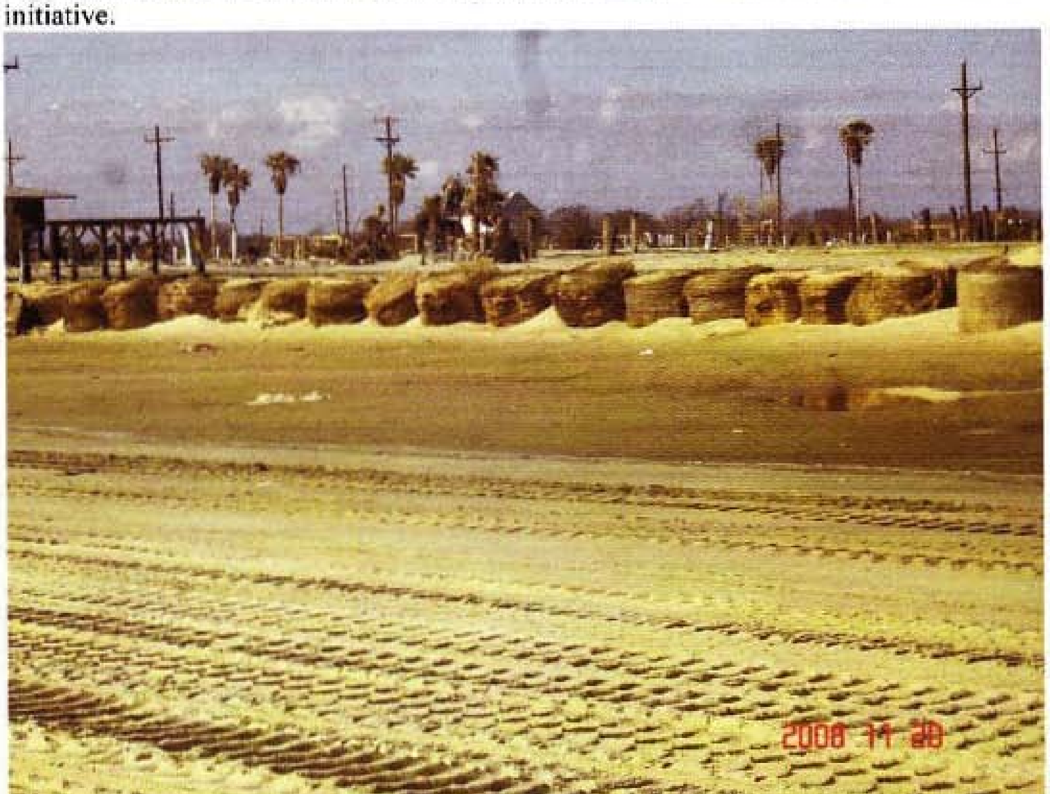

Figure 16. Hay bales used as a dune renourishment initiative on Bolivar Peninsula.

Figure 17. Post-Hurricane Ike photograph of a wide, heavily storm-scoured, compacted beach on Galveston Island.

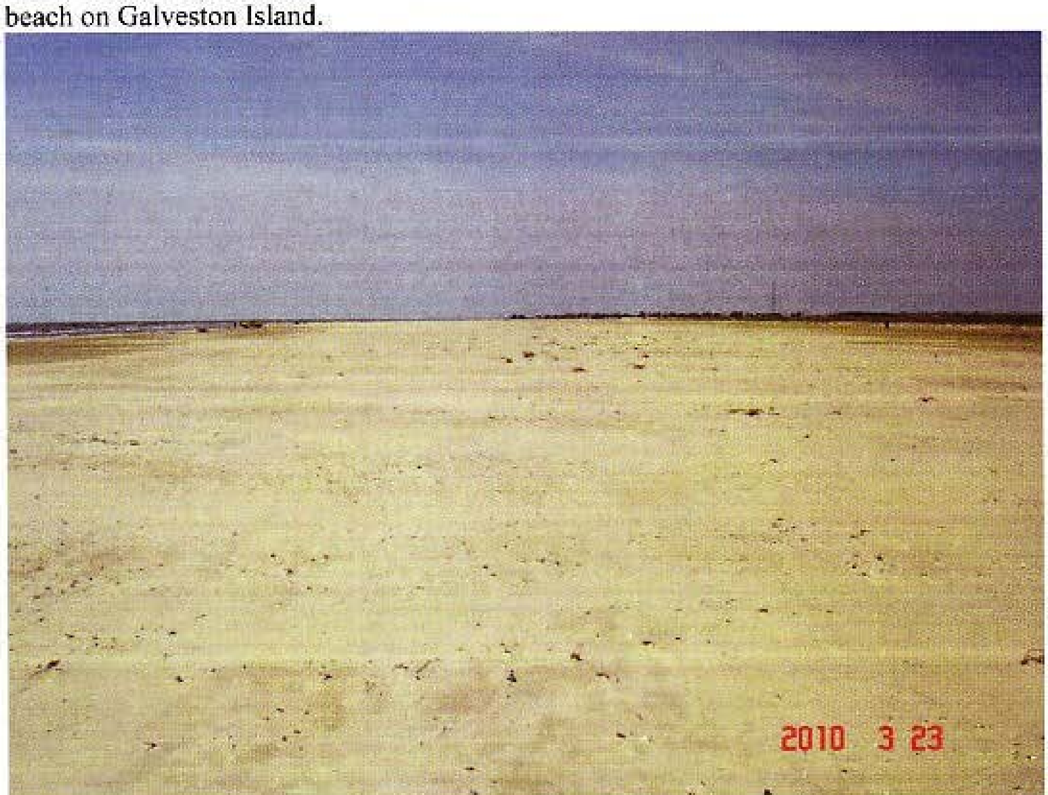

Figure 18. Post-Hurricane Ike photograph of a wide sandy beach on West Galveston Island near San Luis Pass.

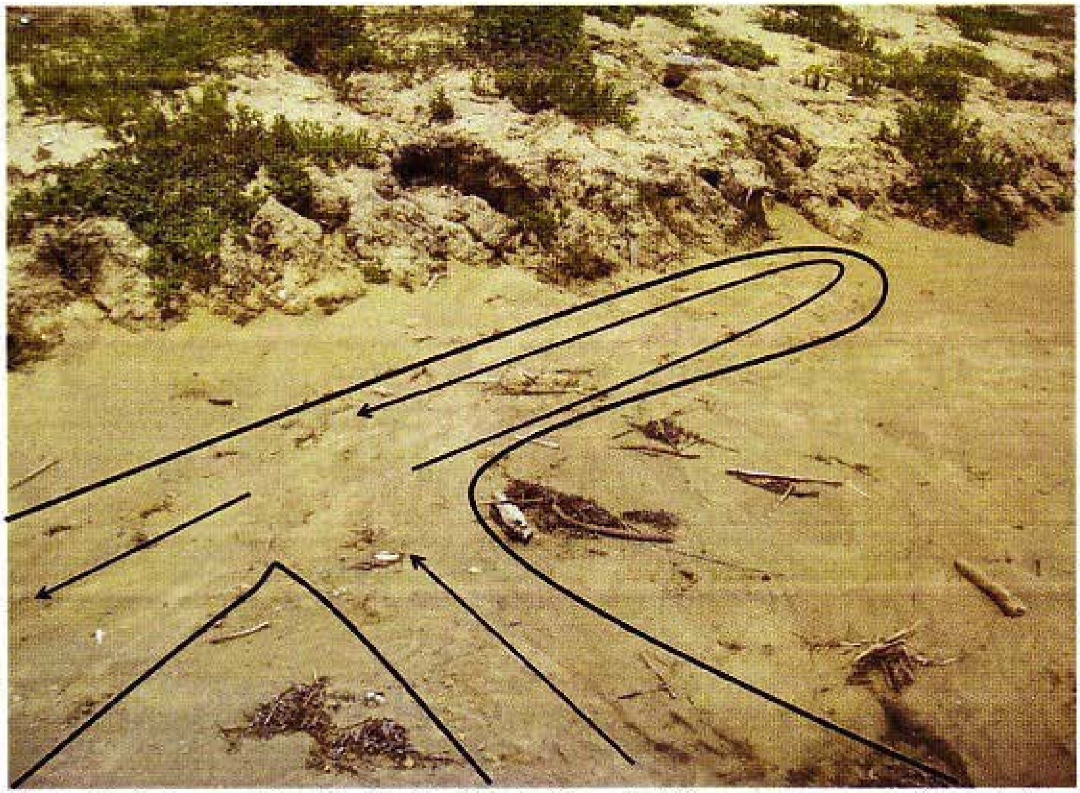

Figure 19. False crawl (outlined in black) of a Kemp's ridley nester on scoured substrate at Hershey Beach on West Galveston Island 2 May 2009.

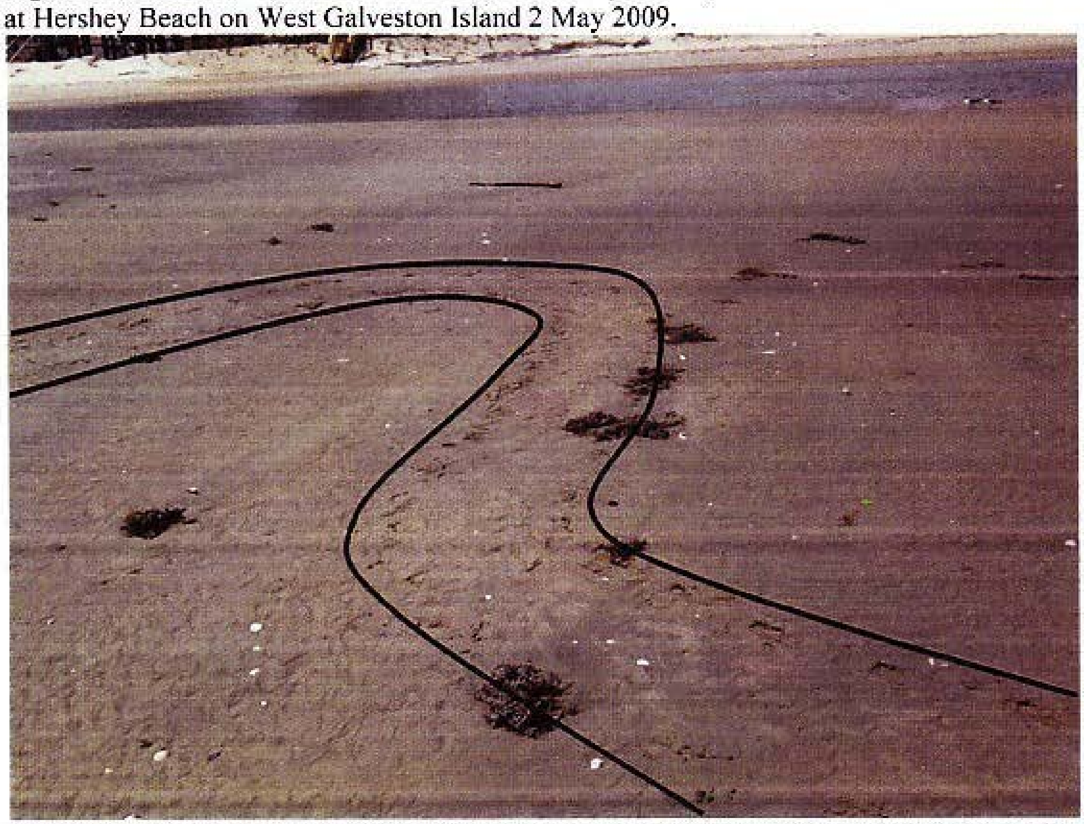

Figure 20. Circuitous aborted crawl of sea turtle approaching inundated beach at San Luis Pass.

Figure 21. Example of beach habitat devoid of dune development on West Galveston Island.

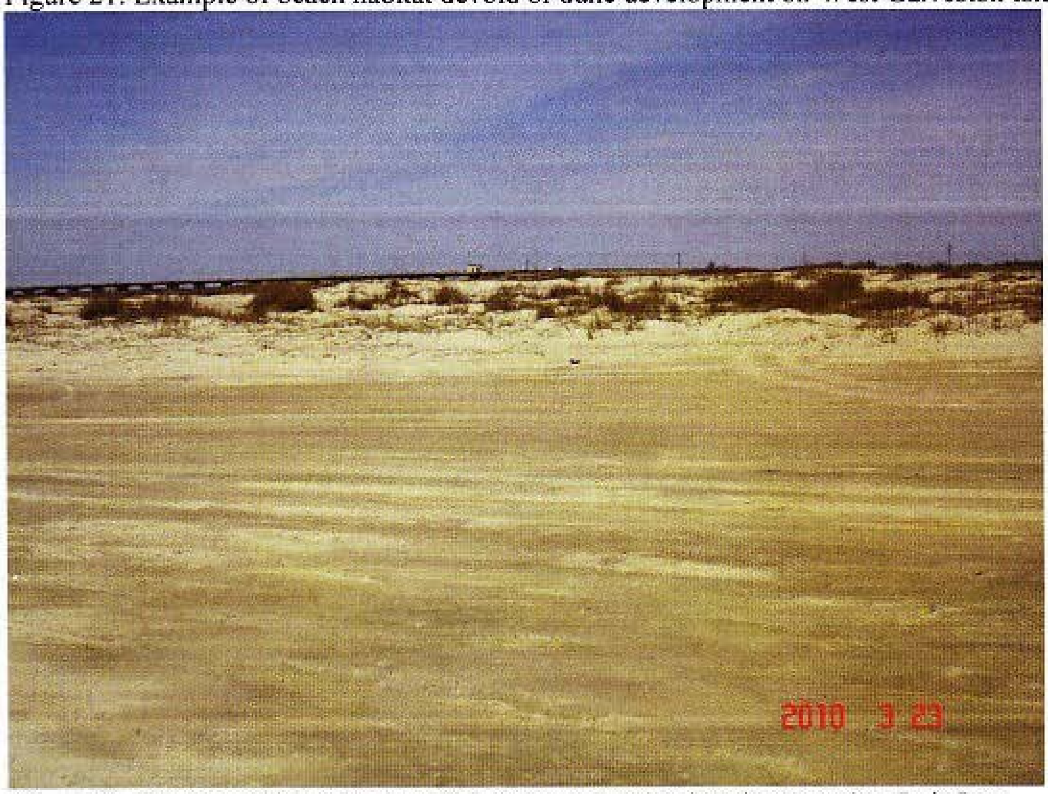

Figure 22. Fairly well developed sand dunes on accreting beaches near San Luis Pass.

Figure 23. Sand dunes lacking vegetative cover and dune crossovers on West Galveston Island.

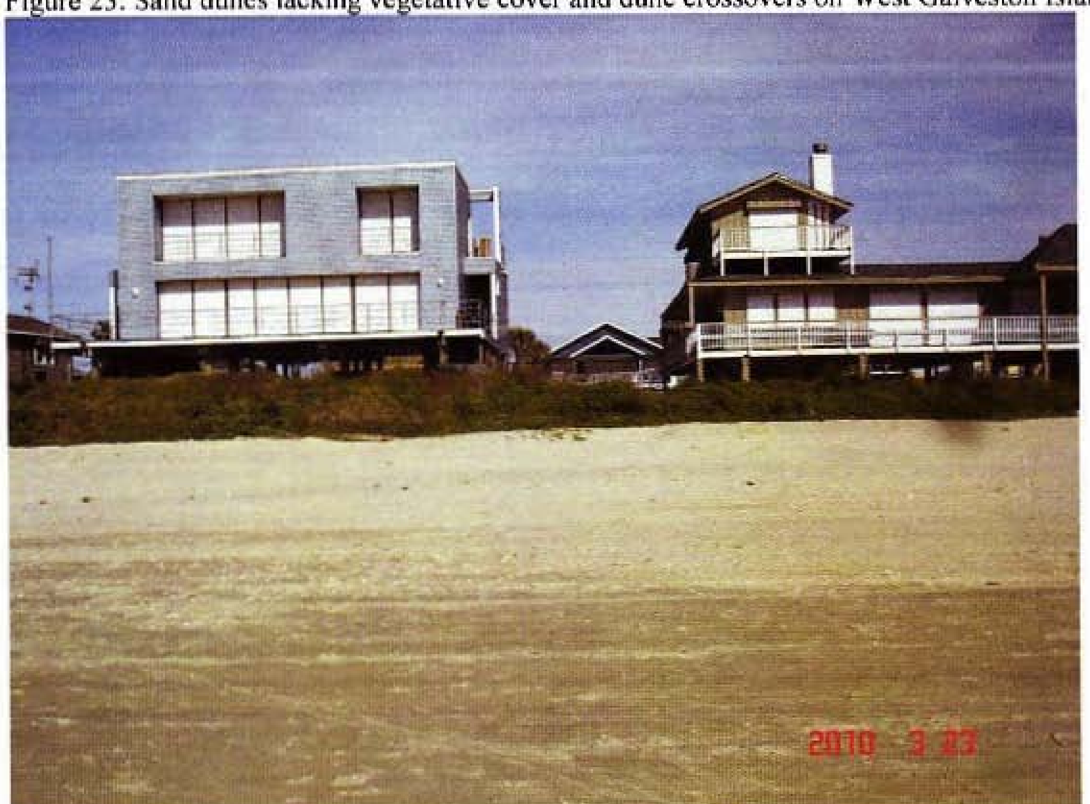

Figure 24. Sand dunes with dense vegetative cover on West Galveston Island.

Figure 25. Sand dunes covered with salt sensitive St. Augustine grass on West Galveston Island.

Figure 26. Well designed sand dune with salt-compatible vegetative cover on West Galveston Island.

Figure 29. Assortment of sand accreting features including perpendicular and parallel fences bordering rows of planted vegetation on West Galveston Island.

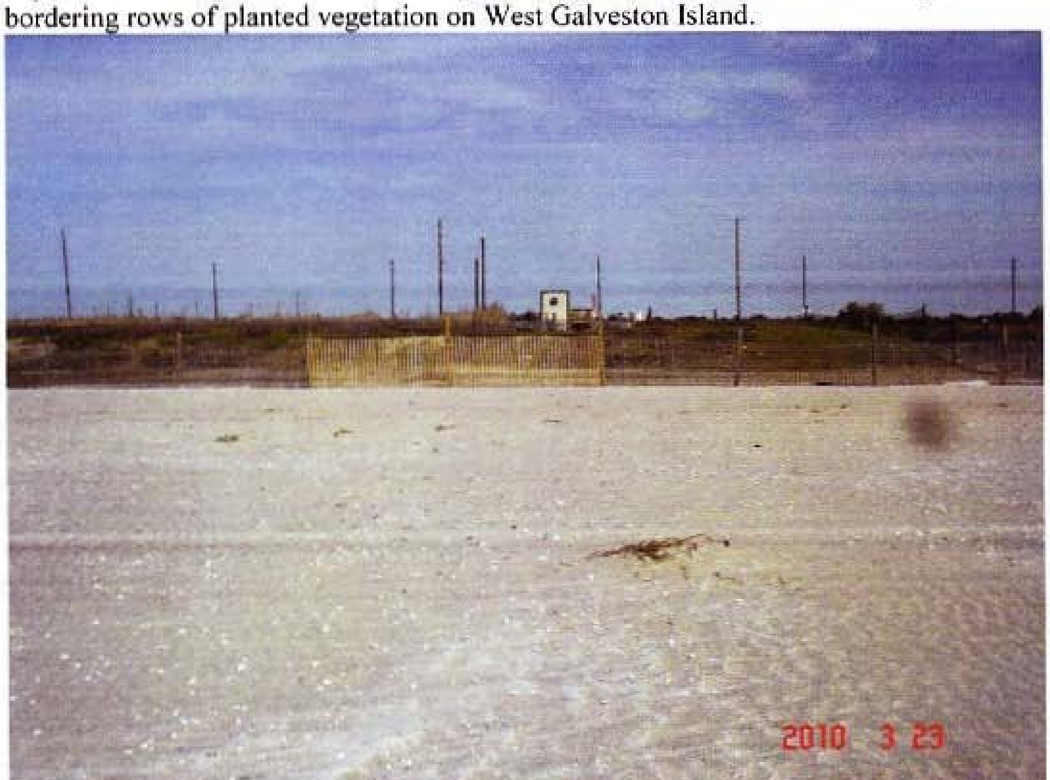

Figure 30. Solid line of closed sand fencing oriented parallel to dunes on West Galveston Island.

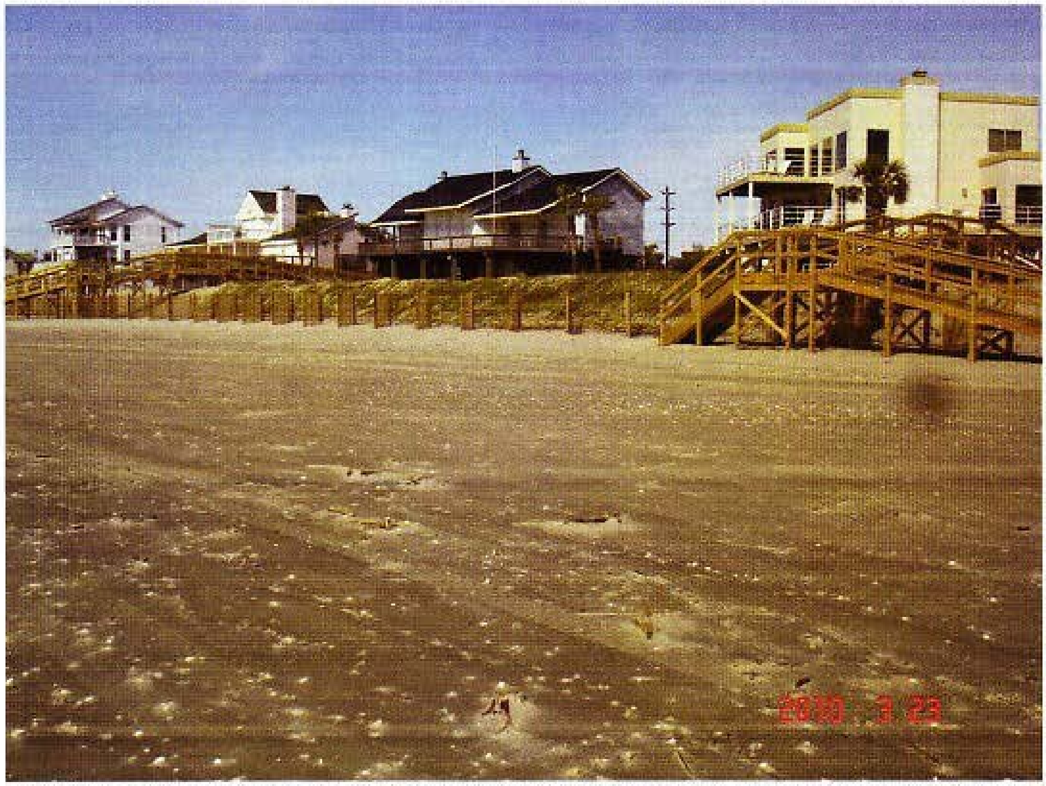

Figure 31. Well designed dune crossover ramps and sand fences on West Galveston Island.