GUIDE TO MANAGING SEA TURTLE NESTING HABITAT ON THE UPPER TEXAS COAST

Final Report to the Texas General Land Office
Coastal Management Program
Grant Cycle #12

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Final Report to the

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***Abstract* –** Annual increases in nesting activity on the upper Texas coast have coincided with recent exponential increases in the Kemp's ridley sea turtle population. Heavily populated and utilized beaches along the upper Texas coast warrant the implementation of sea turtle nesting habitat management policies that minimize potential negative interactions between this growing assemblage of nesters and other user groups. To assist in developing these management policies, four critically important parameters (vegetation coverage, beach width and slope, beach nourishment, artificial lighting) affecting sea turtle reproductive success were identified and documented during observational surveys characterizing nesting habitat quality on a 38.96-km long segment of Bolivar Peninsula in 2008. In addition, Bolivar Peninsula beaches were examined to determine dune ecosystem health, obstacles to nesting, residential development, and substrate quality. Nine distinct habitat zones comprising 18.7% of Bolivar Peninsula were qualified as poor, 13 sections (36.3%) were classified as fair, and 19 sections (45.1%) were categorized as good nesting habitat. ATV-facilitated sea turtle nesting patrols were formally implemented on Bolivar Peninsula in 2008 to document nesting activity. Examination of historical nesting activity on Bolivar Peninsula through 2008 revealed poor habitats remained unutilized by Kemp's ridleys (0.00 nests/km), 3 nests were deposited in fair habitats (0.21 nests/km), and 6 nests were laid in good habitat (0.40 nests/km). Management recommendations to maintain and/or improve nesting habitat quality on Bolivar Peninsula and other upper Texas coast beaches include: nourishment with sand simulating natural sediment properties to maintain beach width; restoration of native dune and plant communities to minimize erosion and enhance sea turtle reproductive success; setback regulations limiting coastal development to reduce light pollution and maintain ecological conditions suitable for nesting turtles and emerging hatchlings; solid waste management policies to reduce obstacles to nester and hatchling movement and improve beach aesthetics; and regulations limiting beach vehicular traffic to improve beach habitat safety for sea turtles and beachgoers. The current protocol for management and care of nests laid on the upper Texas coast involves the high-risk, long distance transport of clutches to Padre Island National Seashore for incubation and subsequent hatchling release. This nest management strategy should be periodically assessed in light of other alternatives involving either lower-risk, local transport of nests to a protected corral or nests left in situ wherein no transport is required. State and federal management agencies should carefully examine recommendations presented for beach habitat and nest product management in light of socioeconomic and environmental concerns as their decisions will significantly impact local economies, particularly in regard to sea turtle-related tourism activities with significant potential to generate increased revenue benefiting local communities.

INTRODUCTION

Annual nesting on the upper Texas coast (herein defined as beaches from Sabine Pass to Matagorda Peninsula) by the critically endangered Kemp's ridley sea turtle (*Lepidochelys kempii*) (Schmid et al., 2003; Marquez et al., 2005) since 2002 has coincided with recent exponential increases in the reproductively viable segment of the population (Marquez et al., 2005; Shaver, 2005; Seney and Landry, 2008). Record nesting activity by the Kemp's ridley has occurred annually since 2004 on both the upper Texas coast and the entire Texas coast, with this trend mirroring recent annual increases in the number of nests deposited on the ridley's primary nesting beach at Rancho Nuevo, Tamaulipas, Mexico (Luis Jaime Pena, Gladys Porter Zoo, Brownsville, TX., pers. comm.). Except for 2 loggerhead turtle (*Caretta caretta*) nests deposited on Bolivar Peninsula (1 apiece in 1996 and 2008), all other 59 sea turtle nests historically documented on the upper Texas coast have been laid by Kemp's ridleys.

Continued recovery of the Kemp's ridley population will further augment sea turtle nesting activity on upper Texas coast beaches such as those along Bolivar Peninsula. Increased likelihood for interaction between this growing assemblage of nesters and rapid development of the upper Texas coast mandates implementation of management policies meeting the needs of human-user groups while reducing impacts to nesting sea turtles. Upper Texas coast beaches characterized by heavy public use and development require management strategies that differ markedly from those currently utilized on ridley nesting beaches at Rancho Nuevo and Padre Island National Seashore (PAIS), Texas, that benefit from government-mandated protection limiting public access and development. This final report, with its emphasis on Bolivar Peninsula, provides guidance to state and federal agencies responsible for addressing the unique sea turtle nesting habitat management challenges that exist on the upper Texas coast.

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). Northern expansion of Kemp's ridley nesting activity onto upper Texas coast beaches such as Bolivar Peninsula has precipitated questions regarding natal beach fidelity and the establishment of a nesting assemblage complementing those at Rancho Nuevo and PAIS. The Kemp's ridley's ongoing recovery trend, when considered in conjunction with its comparatively young estimated age at sexual maturity [10-16 years (Zug et al., 1997; Snover et al., 2007)], emphasizes the need for recent information relevant to the management of nesting beach habitats on the upper Texas coast. This need is particularly acute in the effective management of open access beaches experiencing high levels of public use, such as those on Bolivar Peninsula. While coverage of all relevant environmental factors and human activities influencing nesting habitat on upper Texas coast beaches is beyond the scope of this paper, those identified as critically important (vegetation coverage, beach slope and width, beach nourishment, artificial lighting) are summarized below.

Vegetation Coverage.

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).

Beach Width & Slope.

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 exposed to negative impacts associated with infrastructure as well as increased risk of nest overlap and 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 14 nests documented at hatching through 2007 have been located high on the beach protected from tides (Shaver, 2008), indicating that sufficiently-wide beaches free of tidal inundation are crucial for ridley nesting success in Texas.

Beach Nourishment.

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.

Artificial Lighting.

Nocturnal illumination of nesting beaches by artificial lighting associated with beachfront development negatively impacts sea turtle nesting habitat (Santos et al., 2006) and reproductive success. Nocturnal nesting activity is depressed on artificially illuminated beaches (Salmon et al., 1995; Bertolotti and Salmon, 2005); unnatural lighting can disrupt nest site selection, increase non-nesting emergence ratios, and disorient females (Santos et al., 2006). Nocturnally emerging hatchlings, while able to locate and enter the sea within minutes on dark beaches, often perish due to dehydration, exhaustion or predation as misorientation (hatchlings crawling toward light source) or disorientation (hatchlings crawling in circuitous paths) caused by artificial lighting results in seafinding failure (Horrocks and Scott, 1991; Bertolotti and Salmon, 2005; Tuxbury and Salmon, 2005).

Hatchling seafinding behavior is primarily controlled by two visual cues: contrast in luminosity between landward and seaward horizons, and dissimilarity in landward and seaward horizon elevation (Salmon et al., 1995; Bertolotti and Salmon, 2005; Tuxbury and Salmon, 2005). Vegetated dunes on natural beaches absorb light, aiding hatchlings in orienting toward the naturally brighter reflective ocean surface. Potentially more influential than light intensity cues is orientation of hatchlings toward the lower seaward horizon and away from elevated solid silhouettes, such as those created by dunes or stands of trees. Background illumination, naturally occurring with a full moon, aids hatchlings in differentiating between seaward and landward horizons and enables accurate seafinding regardless of light pollution when adequate horizon cues exist (Bertolotti and Salmon, 2005; Tuxbury and Salmon, 2005). Hatchlings exposed to discrete light sources typically misorient; disorientation occurs when the landward silhouette is low and/or irregular, as when dunes are impaired or absent or with the occurrence of spaced structures on developed beaches (Salmon et al., 1995).

RESEARCH OBJECTIVES

Recent increased use of Bolivar Peninsula beaches by nesting sea turtles accentuates the need for current data detailing impacts of the aforementioned environmental variables and anthropogenic beach activities on nesting habitat quality for management purposes. Funds provided by a CMP Cycle #12 grant to TAMUG permitted the following research objectives to be addressed on Bolivar Peninsula in 2008:

1. To identify beach stretches with the highest sea turtle nesting potential.
2. To identify beach segments whose nesting potential should be improved.
3. To identify beach sections lost to nesting because natural phenomena or man-made alterations have rendered them unattractive to nesting or pose a threat to survival of a nest and its contents.

METHODS

Beach Survey.

Data detailing specific attributes of all Bolivar Peninsula beaches patrolled by TAMUG in 2008 were collected during an ATV-facilitated survey conducted 21 July 2008. Parameters justifying inspection were chosen on the basis of an extensive literature review of environmental and anthropogenic variables known to impact sea turtle nest site selection and nesting success, and are similar to those quantified by Santos et al. (2006). Visual observations were made regarding beach width and slope; dune height, width, and vegetation coverage; nourishment activity; obstacles to nesting, nest success, and/or hatchling emergence; pedestrian and vehicular traffic; and commercial and residential development. This classification method of visual assessment and categorical qualification of pertinent beach parameters is similar to that employed by de Araujo and da Costa (2008). Relevant locations were marked with a Garmin GPS 72, converted to decimal degrees (WGS84) format, and mapped with Google Earth 5.0.

Data Compilation & Mapping.

Bolivar Peninsula beaches were partitioned into variable-length sections based upon the occurrence of homogenous characteristics recorded during the aforementioned beach survey. Sections were then categorically qualified as follows:

good, if there were no strong deterrents to nesting;
fair, if a balance of negative and positive habitat characteristics was identified; and
poor, if negative aspects of the habitat were perceived to exert an overriding influence on sea turtle nesting habitat quality.

To avoid bias in habitat quality determinations, all 11 historical nesting locations documented on Bolivar Peninsula through the 2008 sea turtle nesting season, obtained from GPS data or verbiage recorded on the “Texas Data Sheet For Sea Turtle Tracks and Nests” developed by Dr. Donna Shaver (Chief, Division of Sea Turtle Science and Recovery, Padre Island National Seashore, Corpus Christi, Texas), were converted and plotted only after these beach sections had been formally characterized as either good, fair or poor. Additionally, data regarding 3 documented false crawls (1 in 2002, 2 in 2008) were obtained from the same source and plotted on habitat quality maps for comparison purposes.

RESULTS

Quality of Sea Turtle Nesting Habitat.

Beaches comprising the 38.96-km (24.2-mi) region of Bolivar Peninsula patrolled by TAMUG are characterized by visible evidence of various anthropogenic activities, particularly those associated with vehicular traffic, beach grooming, beachfront residential development, and increased seasonal usage by tourists and residents, all of which may visually deter nesters (Table 1, Figures 1-3). Vehicular traffic, a potential source of mortality for nesters and hatchlings, is facilitated by an open beach policy and multitude of public beach access points distributed throughout the surveyed area and is particularly heavy near access points associated with the extreme eastern and western sections (B1, B2, B42) and Rollover Pass (B32). Beachfront residential developments of varying magnitude occupy all sections with the exception of those on the eastern and western endpoints of the surveyed beach (B1-B3, B40-B42). Artificial lighting sourced from these inhabited structures varies in intensity with housing density and proximity to the tide line, but is clearly visible from all beaches and poses a threat to nocturnally emerging hatchlings and nesters, particularly loggerheads. Beaches west of Rollover Pass contain an even distribution of approximately 98 refuse disposal stations, typically composed of 2 large circular receptacles mounted on 10.2 cm x 10.2 cm (4 in x 4 in) posts immediately adjacent to the dune line; these stations occur with reduced frequency east of Rollover Pass. While these minor obstacles have a small individual footprint, their density increases the potential to limit nester access to dune nesting habitats. In addition to Rollover Pass (B31), an artificial waterway constructed to connect Galveston Bay with the Gulf of Mexico that contains no nesting habitat, 41 distinct sections ranging in quality from good to poor were identified along the surveyed zone.

While moderately wide beaches bordered by partially to fully vegetated dunes of low to moderate height are typical of Bolivar Peninsula, 9 sections (B2, B28, B32, B33, B35, B36, B37, B38, B39) comprising 18.7% (7.25 km) of available nesting habitat were qualified as poor (Tables 1-3, Figures 1-3). With the exception of sections B2 and B39, nesting habitat on these eroded beaches is severely compromised by geotextile tubes or geotubes (Feagin, 2005) installed to protect residential development from frequent tidal inundation (Figure 4). These geotubes, which eliminate dune nesting habitat, are partially to fully exposed by wave action and thus lack the sand and vegetative covering characteristic of natural dunes. In addition, wooden dune crossovers designed to facilitate public beach access traverse geotubes bordering these sections. While crossover design varies considerably, the beachside footprint of many is sizeable, increasing their potential to block nester access to preferred nesting habitat at the base of the geotube (simulated dune line) and magnifying the entrapment hazard for hatchlings. Section B39 contains an adequately wide beach constrained by a sand-covered, vegetated geotube of reduced height; however, this section (and all sections to the east) contains substrate with a high shell content, a drastic alteration from the small sand particles composing beaches in sections B1-B38. Substrate consisting mainly of large shell shards may deter nesters, interfere with nest excavation (Garmestani et al., 2000) or negatively affect hatching and emergence success of hatchlings through altered incubation properties. Section B2 lacks a geotube (as do all western sections) but contains Rettilon Road, the first public beach access east of the ferry landing. Heavy vehicular traffic and associated sand compaction at this access point, combined with the potential for nester visual disorientation created by the relocation of dunes approximately 135-180 m (147.6-196.9 yd) from the high tide line, negatively affect the quality of this section’s beaches.

Figure 4. Poor habitat quality section (B28) impaired by geotube (under high tide conditions 9 June 2008) and geotube crossover obstacle (in foreground). (Photo by Christi Hughes.)

Thirteen sections (B1, B6, B9, B12, B20, B21, B26, B29, B30, B34, B40, B41, B42) incorporating 14.09 km (8.8 mi), or 36.3% of the surveyed zone, were classified as fair nesting habitat (Tables 1-3, Figures 1-3). Section B1 contains low, well-vegetated dunes bordering the undeveloped Bolivar Flats Shorebird Sanctuary, where heavy vehicular traffic from Rettilon Road (B2) may endanger turtles traversing this wide beach and inhibit nest excavation through substrate compaction. Beach raking and scraping activities on four sections (B6, B9, B12, B21) frequently deposit large quantities of sand against the base of dunes, preventing vegetative growth and stabilization of the dune face and drastically reducing or eliminating hatchling emergence potential from in-situ nests covered by material after nest deposition. Nester access to dune nesting habitat is eliminated on four sections: the sand fence confining section B20 is situated parallel to the tide line and void of accreted sand beachside, and geotubes span the moderate-width beaches of sections B29, B30, and B34. Nester and hatchling movement is impeded by dune or geotube crossovers on 7 sections (B6, B9, B12, B21, B26, B29, B34), with 2 substantial structures on section B26 increasing the potential for turtle entrapment. The substrate of three sections contains prodigious quantities of shell (B40) or shell/gravel mixture (B41, B42) that may hinder nest excavation (Garmestani et al., 2000) and reduce in-situ nest hatching success through altered incubation characteristics.

Nineteen sections (B3-B5, B7, B8, B10, B11, B13-B19, B22-B25, B27) containing 17.50 km (10.9 mi) of beach characterized as good nesting habitat are confined to the western and central portions of the surveyed zone and constitute 45.1% of total available habitat (Tables 1-3, Figures 1&2). All lack engineered erosion control structures and, instead, contain vegetated dunes of low to moderate height. However, beach grooming activities that endanger in-situ nests through deposition of sand at the dune line have prevented vegetation from colonizing and stabilizing dune faces on 12 sections (B7, B8, B10, B11, B14-B19, B22, B25). Three sections (B3, B10, B13) intermittently contain washouts that vary in volume and depth with tidal inundation; beaches containing pooled water above the high tide line may deter nesters and increase non-nesting emergence rates. While residential developments have been constructed well behind the current dune line on most of these sections, homes located in close proximity to the dunes on four sections (B15, B17, B19, B22) represent a landward barrier prohibiting natural dune migration and contribute artificial light pollution on adjacent beaches.

Historical Nesting Patterns.

Historical nesting patterns differentiate Bolivar Peninsula from all other upper Texas coast sea turtle nesting habitats. With the documentation of nesting activity by a loggerhead on 27 July 1996, Bolivar Peninsula was utilized by nesting sea turtles a minimum of 8 years prior to the recorded use of all other Texas beaches south to and including Matagorda Peninsula, and remains the only upper coast site where nesting by a species other than the Kemp's ridley is known to have occurred (Table 4). Since 1996, 9 Kemp's ridley nests, 2 loggerhead nests, and 3 false crawls have been documented within the 38.84 km (24.1 mi) surveyed zone (Figures 5-7), resulting in an average of 0.28 nests per kilometer of available habitat (Table 2). The majority of this activity (6 Kemp's ridley nests, 1 loggerhead nest, 2 false crawls) was documented in 2008 following the institution of formal nesting patrols by TAMUG.

A loggerhead nest deposited within section B33 on 24 June 2008 constitutes the sole nest located in habitat herein qualified as poor (0.14 nests/km; Table 2); no Kemp's ridley nests have been documented in poor habitat (Table 3). While section B33 is characterized by residential development protected from tidal inundation by an exposed geotube, the visual attributes of the specific nest site differ significantly from those of the general zone (Figure 8). The nest site, centrally located between poorer quality portions of beach, lacked the visual deterrent of residential construction and contained a fully covered segment of geotube that more closely resembled a natural dune. Nesting activity by Kemp's ridleys along habitat qualified as fair (0.21 nests/km) was significantly less than that documented on beaches classified as good (0.34 nests/km; Table 3). In addition, two of three documented non-nesting emergences occurred in fair habitats. On 7 May 2002, a nester encountering a large branch near dunes in section B1 returned to the Gulf without laying eggs. On 13 May 2008, a female encountering pooled water above the tide line on section B6 also failed to deposit eggs (Figure 9); data suggest this female successfully nested on section B4 (good habitat) the following day. A nest discovered while hatching on 16 July 2008 in fair habitat on section B12 was laid in the foredune depression less than 2 m (6.6 ft) east of a paved beach access road leading into a well-developed residential area. However, it is not clear if the female traversed the dunes or travelled approximately 7 m (23.0 ft) along the sandy access road before turning east to access an unvegetated dune nest site. Individual nests have also been located in fair habitat of sections B6 (30 May 2008) and B40 (24 May 2007); the remaining 6 Kemp's ridley nests, 1 loggerhead nest, and 1 false crawl were located in good habitat.

DISCUSSION

Management of Threats to Sea Turtle Nesting Habitat.

Beach Erosion and Nourishment: Huang's (1997) findings that current shoreline loss rates accelerated by anthropogenic influences on coastal erosion, including subsidence and predicted sea level rise, will leave beach habitats confined by a landward barrier of residential development vulnerable to associated ecological ramifications and infrastructure increasingly susceptible to damage from environmental hazards are applicable to Bolivar Peninsula. Because natural plant and dune migration processes are prevented by hardened structures, remedies such as beach nourishment are required to maintain beaches functionally useful for both humans and sea turtles. Minimizing detrimental biological impacts of nourishment on nesting sea turtles and nest products will require implementing a scientifically rigorous assessment process on the upper Texas coast that utilizes standardized methodology to analyze cumulative effects of nourishment activities.

Biological, physical, and chemical characteristics of a nourished beach are largely determined by sand source and application technique; ideally, fill material should simulate natural sediments (Crain et al., 1995; Montague, 2008). Sea turtle nesting success is correlated with nest microhabitat quality; it is critical that pertinent sediment parameters be analyzed before, during, and after application of fill material, as post-nourishment restoration of natural sediment attributes may be impossible (Peterson and Bishop, 2005). When possible, nourishment activities should only occur outside of nesting season to avoid inherent detrimental impacts associated with increased activity, artificial lighting, construction equipment, and inadvertent burial of in situ nests. Projects occurring on the upper Texas coast between 1 April and approximately 15 August will require turtle monitors to minimize possible negative interactions with nesters and hatchlings. Dissipation of steep scarps will occur naturally as beach profiles normalize (Crain et al., 1995); nonetheless, scarps functioning as obstacles to nesters accessing beach habitats should be removed manually.

Nourishment is an appropriate solution to erosion of multiple poor sections on Bolivar Peninsula typified by narrow beaches with enhanced potential for tidal inundation of nests (B28, B32, B33, B35, B36, B37, B38; Table 1, Figures 2 & 3). It was employed as a temporary but effective solution in May and June 2008 for section B29 that, while characteristically similar to the aforementioned sections, is currently qualified as fair since it provides females with nest placement locations at varying distances above the high tide line. Although an informational void exists regarding preferred beach width parameters for ridleys nesting on the upper Texas coast, nests at Rancho Nuevo are typically laid 10-35 m (10.9 – 38.3 yd) from the tide line (Marquez-M., 1994). As ridleys preferentially nest between the base and top of the first dune (Marquez-M., 1994), this may approximate the ideal crawl distance necessary to access dune habitat and serve as a rough estimate for beach extension distance on the upper Texas coast. The provision of adequate beach width (i.e., one that enables spatially diverse nest excavation options beyond the mean high tide line) is critical for undetected nests; all 14 nests successfully incubated in situ and detected while hatching on the Texas coast through 2007 (Shaver, 2008), as well as 2 in situ nests successfully incubated on Bolivar Peninsula in 2008, were laid high on the beach in areas typically free of seawater washover. While previous research (Rumbold et al., 2001; Brock et al., 2008) indicates non-nesting emergence frequency is significantly increased on beaches during the first nesting season post-nourishment and subsequently decreases as natural processes restore beach slope equilibrium, no data regarding false crawls on nourished beaches currently exist for the upper Texas coast, much less Bolivar Peninsula.

Dune Habitat and Vegetation Coverage: Beach ecosystems managed to retain their natural morphology provide numerous multifaceted, crucial benefits to adjacent coastal communities and multiple user groups, including beachgoers and sea turtles. For upper Texas coast economies reliant on tourism dollars, beach aesthetics improved by dunes and native plant communities are critical in attracting visitors to coastal regions. The presence of vegetation is essential for land management purposes associated with the Texas Open Beaches Act § 61.011, as the vegetation line delineates boundaries separating public and private coastal property. In addition, dunes function as natural buffers against storm systems and, thus, may financially benefit communities by protecting home and business owners from negative impacts associated with storm-induced wave action.

Vegetated dunes provide a favorable environment conducive to sea turtle nesting and overall reproductive success. Visual composition of the nesting-beach environment, specifically that produced by dunes, vegetation, and beach width and slope, is a critical component of sea turtle nest site selection. Females detecting unsuitable terrestrial environment conditions during the initial habitat assessment performed immediately before their emergence onto the beach (Pike, 2008) may fail to emerge and instead proceed to an alternative nesting location. Vegetation minimizes substrate compaction levels, and the elevated, darker silhouette created by vegetation and/or dunes (in contrast to the lower, brighter seaward horizon) is a critical component of hatchling seafinding success (Salmon et al., 1995; Bertolotti and Salmon, 2005; Bourgeois et al., 2009). Robust estimates of preferred nest locations along the horizontal beach gradient between the forebeach and second foredune do not exist for Kemp's ridleys nesting on the upper Texas coast. However, 77.8% of historical nests documented on Bolivar Peninsula through 2008 have been laid either at the base of the foredune or in the foredune depression, signifying the potential importance of dune habitat in nest site selection for sea turtles on the upper Texas coast.

Current rates of beach erosion on the upper Texas coast will likely be exacerbated in the near future by anthropogenic factors, including sea level rise and continued loss of native dune vegetation due in part to increasing coastal development (Feagin et al., 2005). Accelerated beach erosion will increase habitat managers' dependence on temporary and costly mitigation measures, such as beach nourishment, to maintain beach widths enabling dune habitat persistence. Cost-effective, long-term beach habitat management strategies must incorporate the maintenance and/or regeneration of natural sand dunes and associated plant communities (Feagin et al., 2005; Ficetola, 2007; de Araujo and da

Costa, 2008; Montague, 2008; Bourgeois et al., 2009; Mazaris et al., 2009), as dune vegetation minimizes erosion, binds sediments, and enhances dune formation (Marquez-M., 1994; Feagin et al., 2005), thus reducing dependence on expensive erosion control measures. Dune restoration also significantly improves sea turtle reproductive success, particularly on developed beaches compromised by artificial lighting, by intensifying hatchling seafinding cues associated with disparities in landward and seaward horizon elevation (Salmon et al., 1995; Bertolotti and Salmon, 2005; Tuxbury and Salmon, 2005).

Restoration of natural dune systems (and adjacent beach width adequate to maintain them) is recommended for a multitude of sections on Bolivar Peninsula, particularly narrow beaches currently bordered by a geotube (B28, B32, B33, B35-B39; Table 1, Figures 2-4). Habitat restoration should incorporate dune building with replanting multiple species of native vegetation, particularly perennial, late successional species capable of binding sediments. Beach raking and scraping activities, which intensify during the co-occurrence of nesting and tourist seasons, have prevented the perpetuation of dune face vegetation on various sections (B6-B12, B14-B19, B21-B23, B25; Table 1, Figures 1-2). The current practice of depositing scraped sand on the dune face should be reevaluated in comparison to alternatives that may benefit sea turtles, as the former endangers undetected in situ nests. Excess sand covering in situ nests may negatively alter incubation temperatures, and hatchlings may be incapable of digging through surplus substrate before succumbing to exhaustion or suffocation. Finally, maintenance of beach width and cohesive dune ecosystems on multiple sections characterized as good or fair (B1, B3-B5, B13, B24, B26, B27, B40-B42; Table 1, Figures 1-3) should be prioritized, as these comparatively healthy natural systems assist in reducing beach erosion and serve as a seed source for associated habitats.

Residential and Commercial Development: Beach environments, particularly those utilized by nesting sea turtles, should be protected from unplanned, uncontrolled development (Ficetola, 2007; de Araujo and da Costa, 2008). Implementation of setback regulations prohibiting development within a defined distance from shore would aid in maintaining natural beach morphology and vegetation and substrate characteristics (Mazaris et al., 2009) critical to sea turtle reproductive success. Setback regulations preserving the natural ecology of beaches susceptible to weather-related disturbances like hurricanes allow them to function as migratory buffers minimizing damage to residential and commercial structures (Fish et al., 2008). Opposition to setback regulations could be minimized with implementation schemes applicable only to future development. Benefits accrued from restricting development of beach habitat include increased tourism revenue for local communities (sea turtle-related tourism is successfully exploited globally on nesting beaches), reduced short- and long-term financial costs associated with hurricane damage, and improved quality of beach environments. Inability of native dune communities to form or persist in front of anthropogenic structures situated near the shore (Feagin et al., 2005) mandates management strategies that promote sea turtle reproductive success, such as maintaining adequate beach width, restoring dunes, and reducing light pollution, be effectively integrated into any plan for commercial or residential development of beach habitat.

Artificial lighting from residential and commercial development is currently the least likely factor to negatively impact upper Texas coast nesting beaches. However, expected increases in sea turtle nesting and continued beachfront development will amplify the detrimental effects of lighting on sea turtle reproductive success if light pollution is not eliminated or controlled. Implementation of lighting ordinances encompassing the nesting and hatching season (approximately 1 April – 15 August) would aid survival and seafinding of hatchlings emerging from in situ nests by reducing mortality associated with lighting-induced misorientation and disorientation. While lighting is unlikely to affect diurnally nesting Kemp's ridleys, previous research has shown the majority of this species' nest emergences occurs between 0200 and 0400 (Jaime Pena, Gladys Porter Zoo, Brownsville, Texas, pers. comm.), thus justifying the need for lighting ordinances on ridley nesting beaches. As nocturnal nesting activity on developed beaches is inversely correlated with lighting (Salmon et al., 1995), lighting restrictions may facilitate an increase in nesting activity by loggerhead females while reducing the potential for nester disorientation, particularly on Bolivar Peninsula. Specifics of lighting ordinances should include extinguishing all non-critical lights; reducing wattage and/or altering luminaire type [i.e. Witherington (1992) demonstrated that low pressure sodium vapor bulbs had no significant effect on nesting when compared to that from mercury vapor bulbs; LED's warrant examination]; and filtering, lowering, and/or shielding light sources to reduce beachside visibility of lights. Integrating lighting ordinances with dune and beach habitat restoration would greatly reduce associated negative impacts as normal hatchling orientation can occur on light-polluted beaches when horizon elevation cues are enhanced (Bertolotti and Salmon, 2005; Tuxbury and Salmon, 2005).

Characterizations regarding the quality of Bolivar Peninsula beach habitats (Table 1) included in this document reflect nesting conditions during 2008 but are not indicative of impact from Hurricane Ike that destroyed upper Texas coastal ecosystems in mid-September 2008. Five of 6 Kemp's ridley nests laid in 2008 were located in sections where development was situated well behind vegetated dunes of moderate height (B4, B5, B6, B16; Table 4); 3 of these nests were in sparsely developed areas with minimum potential for visual deterrence of nesters. In addition, the loggerhead nest documented in 2008 was situated in habitat lacking development within the visual frame of reference utilized by females during nest site selection (Salmon et al., 1995; Figure 8). Although additional research is required to determine the influence beachfront development has on nest site selection, particularly that by Kemp's ridleys utilizing upper Texas coast beaches, results reported herein indicate turtles may preferentially nest on undeveloped or minimally developed beaches containing vegetated dunes. Finally, while conflicts between nesting or hatchling turtles and other anthropogenic structures, such as dune crossovers, have not been documented, beach habitats should be managed to reduce the potential for negative interactions between these federally protected animals and beachside constructions.

Obstacles to Nesting: Visual contamination of beach habitats by solid waste from terrestrial and oceanic sources, particularly plastics (Figure 10), is of widespread and growing global concern due to its negative effects on tourism and wildlife, including sea turtles (de Araujo and da Costa, 2008). Ensuring an aesthetic state of Texas' beaches should be of significant concern to upper coast economies dependent upon income generated by tourism. Beach litter may visually deter nesting females or serve as an obstacle to nest site selection and/or digging (Santos et al., 2006), subsequently increasing the incidence of non-nesting emergences (Montague, 2008). Refuse creates a significant obstacle to a hatchling's forward movement, potentially increasing time necessary to access the sea and thus reducing survivorship by increasing predator exposure (Montague, 2008). Upper Texas coast beaches, associated wildlife, and corresponding local economies would benefit significantly from remediation of refuse-strewn beach habitats; supplementations to current beach cleanup efforts include bolstering and enforcement of beach litter policies and public education efforts aimed at source reduction.

Figure 10. Typical Bolivar Peninsula beach habitat (section unknown) littered with refuse following post-holiday tourism activity (photo taken on 7 July 2008 by Christi Hughes).

Anthropogenic structures constructed on beach habitats also may pose an obstacle to sea turtle reproductive success (Marquez-M., 1994; Santos et al., 2006). A multitude of beach sections on Bolivar Peninsula (B4-B6, B9, B12, B21, B26, B28, B29, B32-B37; Table 1, Figures 1-4) contain dune or geotube crossovers enabling public beach access while preventing damage to dune habitats. While the majority of Bolivar Peninsula's crossovers are designed to minimize their footprint on beach habitat, a significant number are constructed in a manner that maximizes the potential to obstruct nester and hatchling movement (Figure 4). Entrapment by crossovers is a potential source of mortality (due to hyperthermia during daylight hours) for nesters and hatchlings. Emerging hatchlings may also fail at seafinding due to disorientation or misorientation sourced from the visually altered landscape created by crossovers. These concerns mandate that construction of new dune crossovers occur only as needed and employ designs minimizing impacts to sea turtles.

Finally, policies permitting vehicular traffic on beach habitats, particularly those utilized by nesting sea turtles, are of great concern (Santos et al., 2006). Currently, vehicular traffic is allowed on all surveyed sections of Bolivar Peninsula and is encouraged through the provision of numerous beach access points. To date, Texas' beach driving policies have resulted in the death of three nesting females, including a loggerhead struck and killed after nesting on Bolivar Peninsula (section B22) in 1996. Vehicles also served as a source of mortality for multiple hatchlings emerging from both in situ nests detected while hatching on Bolivar Peninsula (sections B12 and B16) in 2008. The beach-going public's lack of knowledge regarding use of upper Texas coast beaches as nesting habitat is a growing concern. Failure to inform this constituency may lead to an increase in vehicular-related deaths to sea turtles, given the likelihood that the ongoing recovery exhibited by Kemp's ridleys will precipitate increased nesting activity on the upper Texas coast. Habitat managers and policy makers should periodically evaluate the efficacy of instituting spatial and/or temporal driving limitations on Bolivar Peninsula beaches to protect sea turtles. In addition, workers operating machinery on these beaches during nesting season (beach rakers, nourishment crews, etc.) should receive training in sea turtle identification and nesting response.

Management of Sea Turtle Nest Products.

Nearly all detected nests deposited on the Texas coast (with the exception of those on South Padre Island and Boca Chica Beach) are excavated by trained, permitted responders and transported by vehicle to an incubation facility operated by the National Park Service at PAIS. However, multiple management options for sea turtle nest products located on the upper Texas coast exist and should be periodically re-evaluated to ensure implementation and/or continuance of the most viable and appropriate course of action to maximize nest success, as all influence subsequent habitat management decisions.

Nest relocation practices utilized on the upper Texas coast since the 1996 inception of nesting involve excavation and placement of eggs into Styrofoam incubation boxes lined with sand obtained at or near the nest site. These eggs undergo two separate transfers by vehicle to reach PAIS for subsequent incubation and hatchling release during the critical 6-48 hour post-oviposition timeframe identified by Marquez-M. (1994) where inappropriate egg handling can result in lethal deformities and complete nest mortality. While hatching success rates obtained from Bolivar Peninsula nests subjected to cumulative vehicle transport times typically exceeding 6 hours have been comparable to those from nests deposited and incubated at PAIS, this method involves substantial risk to developing embryos. Lethal developmental deficiencies and mortality rates reaching 100% can occur during nest relocation from poor and/or excessive egg handling which results in egg inclination and embryo rotation, vibrations, contamination and/or overheating (Marquez-M., 1994).

State and federal resource managers must carefully consider long-term effects of continued relocation of sea turtle nest products from the upper Texas coast to PAIS, as this practice may endanger the role of constituent beaches as important natal nesting habitat and thus negate the generation of ecotourism dollars and associated educational outreach. While the imprinting process that enables a nester to find her natal beach is not fully understood (Meylan et al., 1990; Marquez-M., 1994; Crain et al., 1995; Shaver, 2002), hatchlings incubated and released at PAIS will likely return to PAIS, and not their natal beach, to nest, thus reducing the potential for increased nesting fidelity to the upper Texas coast. In addition, further increases in number of nests laid on upper Texas coast beaches, combined with expected growth in nesting activity at PAIS, may soon render transfer of clutches to PAIS time- and cost-prohibitive.

Relocation of upper Texas coast nests to a centrally located corral secured against egg poaching and natural predation should be assessed as an alternative to transferring clutches to PAIS. This protocol is utilized effectively at PAIS (Dr. Donna Shaver, pers. comm.), in South Texas (South Padre Island and Boca Chica Beach), and on the ridley's primary nesting beach at Rancho Nuevo. Risk of embryonic mortality associated with egg handling is minimized in clutches relocated to a hatchery within 2 hours of deposition (Eckert et al., 1999). Furthermore, hatching success rates from sea turtle nests relocated promptly can be comparable to nests incubated in situ (Mrosovsky, 2006). Increased hatching and emergence success rates may be obtained with use of improved transport boxes, as occurred with the experimental container used to convey Kemp's ridley eggs described by Vazquez-Sauceda et al. (2008). As such, local relocation poses considerably less risk to nest products than does long-distance translocation to PAIS. More importantly, release of hatchlings imprinted to natal upper Texas coast beaches will preclude the loss of an associated nesting cohort, and will likely contribute to long-term nesting increases, thus creating exploitable ecotourism and public education opportunities with future expansion potential.

An informational void exists regarding the ability of upper Texas coast beaches to provide suitable incubation conditions (thermal regime, hydric environment, sand mineral content, gas exchange, etc.) for sea turtle nests. However, hatching success rates estimated for all 3 in-situ nests detected while hatching on the upper Texas coast, including 2 located on Bolivar Peninsula in 2008, were between 80.6-94.3% (Dr. Donna Shaver, pers. comm.), suggesting that nests can be successfully incubated in constituent habitats. Although multiple benefits are associated with implementing this alternative management strategy, personnel and funding to support corral management, including predator control and 24-hour surveillance of nests approaching estimated hatching dates, would need to be secured.

A nest management strategy whereby nests laid above the high tide line are left in-situ to incubate and hatch without human interference would significantly reduce relocation efforts. While this strategy is successfully utilized in Florida, where tens of thousands of sea turtles annually deposit nests, it is an impractical solution for areas such as the upper Texas coast, where public education related to sea turtles is lacking and low density nesting by the critically endangered Kemp's ridley warrants protection of every nest. The well-planned relocation of nests and immediate release of emerged hatchlings pose significantly fewer threats to nest products than do natural nest predation and environmental variables (Marquez-M., 1994). When considered in conjunction with existing upper Texas coast hazards such as vehicular beach traffic, beach nourishment and grooming activities, compromised dune environments, high levels of beach refuse, and coastal development of homes and associated structures, nest relocation to either PAIS or an upper Texas coast corral currently appears necessary to maximize hatchling production and the continued recovery of the Kemp's ridley.

CONCLUSIONS

Habitat quality along the upper Texas coast, including that on Bolivar Peninsula, significantly impacts economic health of constituent communities dependent upon tourism revenue and the potential to establish a self-sustaining cohort of nesting sea turtles. State and federal agencies responsible for implementing management policies must carefully consider interdependent socioeconomic and environmental concerns in developing strategies for the long-term governance of upper Texas coast beach habitats. While public use of beach environments is very diverse, creation and maintenance of constituent habitats successfully serving a multitude of user groups does not preclude the simultaneous provision of beaches adequately supporting sea turtle reproductive success.

The analysis of Bolivar Peninsula beach habitat quality presented herein represents only a snapshot in time of a dynamic environment susceptible to drastic alterations from both natural and anthropogenic sources. As such, recommendations presented in reference to specific sections should be considered generalizations adaptable to comparable situations. Additionally, while the generation of data specific to nesting beach habitats (particularly recently identified beaches on the upper Texas coast) is of paramount importance to long-term sea turtle conservation practices, managers must realize that the life history strategy and late maturation of these turtles mean it may take decades for effects of management decisions to be apparent.

The evolution of sea turtle management practices on the upper Texas coast will require additional research in relation to the following questions, which are adapted from those originally posed by Santos et al. (2006). First, what actions can be taken to maintain existing high quality nesting habitat in undeveloped areas, and what can be done to improve compromised nesting habitat, particularly in areas with extensive coastal development? Second, if current nest product management procedures are altered to allow eggs laid on the upper Texas coast to remain for subsequent incubation and release, what criteria will be used to identify surrogate incubation habitat? Finally, how much and what kinds of disturbances can turtles, particularly Kemp’s ridleys, tolerate? While current nesting totals indicate that the population of the critically endangered Kemp’s ridley turtle, Texas’ dominant nester, remains significantly reduced from historic abundance levels, the recovery of this species is ongoing. Continued examination of the role of the upper Texas coast in providing nesting habitat to increasing numbers of conspecifics is critical, and must be coupled with successful beach habitat conservation and management plans minimizing conflicts between nesters and other beach user-groups while promoting ecotourism benefiting sea turtles and local economies.

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Table 1. Characterization of Sea Turtle Nesting Habitat Quality on Bolivar Peninsula, Texas.[1]

SECTION	LENGTH (km)	SECTION BEGINNING		SECTION END		NESTING HABITAT CHARACTERISTICS
		Latitude	Longitude	Latitude	Longitude	
🟨 B1	1.10	29.37200	-94.72763	29.38110	-94.72308	+ Low, well-vegetated dunes extend behind beach into bird sanctuary. + No housing development. - Heavy vehicular traffic between Bolivar Flats Bird Sanctuary and Rettilon Road.
🟥 B2	0.30	29.38110	-94.72308	29.38368	-94.72185	+/- Well-vegetated dunes removed 150-200 m from high tide line on overly wide beach. + No housing development. - Extremely heavy vehicular traffic as is first public beach access point east of ferry landing.
🟩 B3	1.34	29.38368	-94.72185	29.39413	-94.71520	+ Well-vegetated dunes of moderate height. + No housing development. +/- Large washout (29.38983, -94.71830) may deter nesters who encounter water pooled on beach.
🟩 B4	1.20	29.39413	-94.71520	29.40282	-94.70808	+ Foredune fronts well-vegetated dune complex of moderate height. + Sparse housing development set well behind dunes begins here and extends east. - Well-constructed dune crossovers present minor obstacle to nesters and hatchlings.
🟩 B5	0.78	29.40282	-94.70808	29.40813	-94.70282	+ Foredune fronts well-vegetated dune complex of moderate height. + Housing development set adequate distance behind dunes. - Low number of well-constructed dune crossovers present minor obstacle to nesters and hatchlings.
🟨 B6	1.70	29.40813	-94.70282	29.41853	-94.69015	+/- Vegetated dunes of moderate height lack vegetation on dune face from beach grooming activities. + Sparse housing development set well behind dunes. - Low number of well-constructed dune crossovers present minor obstacle to nesters and hatchlings. +/- Washout (29.41083, -94.69978) may deter nesters who encounter water pooled on beach.
🟩 B7	1.10	29.41853	-94.69015	29.42467	-94.68130	+/- Vegetated dunes of moderate height lack vegetation on dune face from beach grooming activities. + Housing development set well behind dunes.
🟩 B8	0.40	29.42467	-94.68130	29.42682	-94.67802	+/- Vegetated dunes of moderate height lack vegetation on dune face from beach grooming activities. + No housing development.
🟨 B9	0.67	29.42682	-94.67802	29.43033	-94.67233	+/- Vegetated dunes of moderate height lack vegetation on dune face from beach grooming activities. + Housing development set well behind dunes. - Low number of well-constructed dune crossovers present minor obstacle to nesters and hatchlings.
🟩 B10	0.95	29.43033	-94.67233	29.43497	-94.66423	+ Well-vegetated dunes of moderate height occasionally lack vegetation on dune face from beach grooming activities. + No housing development. +/- Washout (29.43402, -94.66595) may deter nesters who encounter water pooled on beach.
🟩 B11	0.95	29.43497	-94.66423	29.43952	-94.65597	+/- Vegetated dunes of moderate height lack vegetation on dune face from beach grooming activities. + Housing development set well behind dunes.
🟨 B12	0.94	29.43952	-94.65597	29.44387	-94.64765	+/- Low vegetated dunes lack vegetation on dune face from beach grooming activities. +/- Housing development located immediately behind dunes. - Poorly constructed dune crossover near section beginning presents obstacle to nester and hatchlings.

HABITAT QUALITY KEY		
🟩 GOOD	🟨 FAIR	🟥 POOR

[1] **Figure 1 contains satellite images delineating section boundaries and associated habitat.**

Table 1 Cont'd.[2]

SECTION	LENGTH (km)	SECTION BEGINNING		SECTION END		NESTING HABITAT CHARACTERISTICS
		Latitude	Longitude	Latitude	Longitude	
🟩 B13	1.15	29.44387	-94.64765	29.44907	-94.63742	+ Vegetated dunes of moderate height. + No housing development. +/- Washout (29.44740, -94.64087) may deter nesters who encounter water pooled on beach.
🟩 B14	0.52	29.44907	-94.63742	29.45138	-94.63273	+/- Vegetated dunes of moderate height lack vegetation on dune face from beach grooming activities. + Housing development set well behind dunes.
🟩 B15	1.04	29.45138	-94.63273	29.45587	-94.62330	+/- Vegetated dunes of moderate height lack vegetation on dune face from beach grooming activities. +/- Numerous houses located immediately behind dunes.
🟩 B16	1.33	29.45587	-94.62330	29.46150	-94.61115	+/- Vegetated dunes of moderate height typically lack vegetation on dune face from beach grooming activities. + Housing development set well behind dunes.
🟩 B17	0.12	29.46150	-94.61115	29.46202	-94.61002	+/- Vegetated dunes of moderate height typically lack vegetation on dune face from beach grooming activities. +/- Row of six houses located immediately behind dunes.
🟩 B18	0.21	29.46202	-94.61002	29.46293	-94.60805	+/- Vegetated dunes of moderate height typically lack vegetation on dune face from beach grooming activities. + Housing development set well behind dunes.
🟩 B19	0.32	29.46293	-94.60805	29.46420	-94.60518	+/- Vegetated, low to moderate height dunes typically lack vegetation on dune face from beach grooming activities. +/- Numerous houses located immediately behind dunes.
🟨 B20	0.07	29.46420	-94.60518	29.46442	-94.60460	- Sand fence running parallel to water blocks nester access to low, minimally vegetated dunes accreted behind it. +/- Numerous houses located immediately behind dunes.
🟨 B21	0.58	29.46442	-94.60460	29.46680	-94.59923	+/- Vegetated, low to moderate height dunes lack vegetation on dune face from beach grooming activities. + Numerous houses primarily located well behind dunes. - Multiple well-constructed dune crossovers present minor obstacle to nesters and hatchlings.
🟩 B22	0.88	29.46680	-94.59923	29.47035	-94.59115	+/- Well-vegetated dunes of low to moderate height intermittently lack vegetation on dune face from beach grooming activities. +/- Numerous houses located immediately behind dunes.
🟩 B23	2.26	29.47035	-94.59115	29.47920	-94.57012	+ Well-vegetated dunes of low to moderate height display minimal signs of beach raking activities. + Housing development set well behind dunes.
🟩 B24	0.32	29.47920	-94.57012	29.48043	-94.56707	+ Well-vegetated dunes of low to moderate height have accreted around primarily buried sand fence.
🟩 B25	1.85	29.48043	-94.56707	29.48740	-94.54980	+/- Well-vegetated dunes of low to moderate height intermittently lack vegetation on dune face from beach grooming activities. + Two houses located well behind dunes.
🟨 B26	0.16	29.48740	-94.54980	29.48798	-94.54838	+ Well-vegetated dunes of moderate height. +/- Housing development under construction located immediately behind dunes. - Two large dune crossovers present obstacle to nesters and hatchlings.
🟩 B27	0.78	29.48798	-94.54838	29.49093	-94.54102	+ Well-vegetated dunes of moderate height. + Sparse housing development set well behind dunes.
🟥 B28	3.26	29.49093	-94.54102	29.50310	-94.51042	- Beach lacks vegetated dunes; exposed geotube eliminates dune nesting habitat. - Beach width narrow. +/- Western portion contains sparse housing development, eastern portion contains houses located immediately behind exposed geotube. - Mulitple geotube crossovers with large bases present major obstacle to nesters and hatchlings. - Large (5 m x 12 m) geotube crossover (29.49978, -94.51892) situated near tideline presents major obstacle to nesters and hatchlings.
🟨 B29	0.18	29.50310	-94.51042	29.50387	-94.50878	- Beach lacks vegetated dunes; exposed geotube eliminates dune nesting habitat. + Beach width adequate due to nourishment activities in May/June 2008. +/- Housing development located immediately behind exposed geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings.

HABITAT QUALITY KEY		
🟩 GOOD	🟨 FAIR	🟥 POOR

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[2] **Figure 2 contains satellite images delineating section boundaries and associated habitat.**

Table 1 Cont'd.[3]

SECTION	LENGTH (km)	SECTION BEGINNING		SECTION END		NESTING HABITAT CHARACTERISTICS
		Latitude	Longitude	Latitude	Longitude	
B30	0.90	29.50387	-94.50878	29.50690	-94.50033	- Beach lacks vegetated dunes; geotube primarily covered with vegetated sand eliminates dune nesting habitat. + Beach width adequate due to nourishment activities in May/June 2008. +/- Sparse housing development set well behind dunes; two homes situated immediately behind geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings.
B31	0.12	29.50690	-94.50033	29.50727	-94.49862	Rollover Pass - no nesting habitat.
B32	0.24	29.50727	-94.49862	29.50808	-94.49673	- Beach lacks vegetated dunes; exposed geotube eliminates dune nesting habitat. - Beach width narrow; beach fully inundated at high tide. + Housing development set adequately behind geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings. - Heavy vehicular traffic; this is first public access point to beaches east of Rollover Pass.
B33	1.71	29.50808	-94.49673	29.51438	-94.48067	- Beach lacks vegetated dunes; partially to fully exposed geotube eliminates dune nesting habitat. +/- Beach width moderately narrow. +/- Housing development located immediately behind geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings. - Unoccupied house situated on beach in front of geotube (29.51033, -94.49110) presents major obstacle to nesters and hatchlings.
B34	0.46	29.51438	-94.48067	29.51613	-94.47633	- Beach lacks vegetated dunes; geotube covered with vegetated sand eliminates dune nesting habitat. + Beach width moderate. + Housing development set well behind geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings.
B35	0.50	29.51613	-94.47633	29.51793	-94.47152	- Beach lacks vegetated dunes; geotube covered with vegetated sand eliminates dune nesting habitat. - Beach width moderately narrow. +/- Numerous houses located immediately behind geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings. - Geotube crossover constructed parallel to tideline presents major obstacle to nester and hatchlings.
B36	0.66	29.51793	-94.47152	29.52027	-94.46525	- Beach lacks vegetated dunes; primarily exposed geotube eliminates dune nesting habitat. - Beach width narrow; beach fully inundated at high tide. +/- Houses located immediately behind exposed geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings. - Beach substrate composed primarily of shells.
B37	0.27	29.52027	-94.46525	29.52115	-94.46273	- Beach lacks vegetated dunes; geotube covered with vegetated sand eliminates dune nesting habitat. - Beach width moderately narrow. +/- Houses located immediately behind geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings. - Beach substrate composed primarily of shells.
B38	0.12	29.52115	-94.46273	29.52155	-94.46163	- Beach lacks vegetated dunes; exposed geotube eliminates dune nesting habitat. - Beach width moderately narrow. +/- Houses located immediately behind exposed geotube. - Multiple geotube crossovers present obstacle to nesters and hatchlings. - Beach substrate composed primarily of shells.
B39	0.19	29.52155	-94.46163	29.52218	-94.45973	- Beach lacks vegetated dunes; geotube of reduced height covered with vegetated sand eliminates dune nesting habitat. + One house located well behind geotube. - Beach substrate composed primarily of shells.
B40	4.55	29.52218	-94.45973	29.53837	-94.41663	+ Well-vegetated dunes of moderate height contain increased plant biodiversity. + Beach width moderate; increased slope minimizes erosion. + No housing development. - Beach substrate composed primarily of shells.
B41	0.34	29.53837	-94.41663	29.53965	-94.41343	+ Well-vegetated dunes of moderate height contain increased plant biodiversity. + Beach width moderate; increased slope minimizes erosion. + No housing development. - Beach substrate composed of shell/gravel mixture. - Old fishing pier (~3 m wide) at section beginning presents obstacle to nesters and hatchlings.
B42	2.44	29.53965	-94.41343	29.54832	-94.39040	+ Well-vegetated dunes of low to moderate height. +/- Beach width moderately narrow; increased slope minimizes erosion. + No housing development. - Beach substrate primarily shell/gravel mix interspersed with sand grains. - Heavy vehicular traffic as endpoint at intersection of Highways 87 and 124 serves as beach access point.
TOTAL	38.96					

HABITAT QUALITY KEY		
GOOD	FAIR	POOR

[3] **Figure 3 contains satellite images delineating section boundaries and associated habitat.**

Table 2. Sea Turtle Nesting Activity on Bolivar Peninsula Beaches of Various Habitat Quality.

SECTION QUALITY	PERCENTAGE OF ZONE	TOTAL LENGTH (KM)	NUMBER OF NESTS	NUMBER OF NESTS/KM
Good	45.1	17.50	7	0.40
Fair	36.3	14.09	3	0.21
Poor	18.7	7.25	1	0.14
Zone Total	**100.00**	**38.84** [1]	**11**	**0.28**

[1] **Section B31 lacks nesting habitat and is not included in these calculations.**

Table 3. Kemp's Ridley Nesting Activity on Bolivar Peninsula Beaches of Various Habitat Quality.

SECTION QUALITY	PERCENTAGE OF ZONE	TOTAL LENGTH (KM)	NUMBER OF NESTS	NUMBER OF NESTS/KM
Good	45.1	17.50	6	0.34
Fair	36.3	14.09	3	0.21
Poor	18.7	7.25	0	0.00
Zone Total	**100.00**	**38.84** [1]	**9**	**0.23**

[1] **Section B31 lacks nesting habitat and is not included in these calculations.**

Table 4. Historical Kemp's Ridley Sea Turtle Nesting Activity on Bolivar Peninsula, Texas.

NESTING DATE	TIME	LOCATION (WGS84)		NESTING LOCATION	BEACH SECTION	NEST HABITAT	NESTER			
		Latitude	Longitude				SPECIES	Wild or Headstart	SCL[1] (cm)	Primary Tag
27-Jul-96	0300	29.46667[3]	-94.59833	3.2 km (~2 mi) East of Ramada Beach	B22 / Good	Downslope of First Foredune	Loggerhead[4]	Wild[7]	87.5	none
7-May-02	1120	N/R	N/R	0.3 km (~0.2 mi) East of Bolivar Flats Bird Sanctuary	B1 / Fair	N/A (false crawl)	Kemp's ridley[4]	1990 Headstart	64.7	none
11-May-04	1215	29.45450	-94.62652	Crystal Beach	B15 / Good	N/R	Kemp's ridley[4]	1992 Headstart	63.0	RRV311
3-Jun-04	0900	29.38645	-94.72138	0.8 km (~0.5 mi) East of Rettilon Road	B3 / Good	Base of Foredunes	Kemp's ridley[5]	Unknown	N/A	N/A
24-May-07	0740	29.52487	-94.45302	Gilchrist	B40 / Fair	Embryonic Dunes	Kemp's ridley[5]	Unknown	N/A	N/A
25-Apr-08	1013	29.40742	-94.70403	West of Trash Receptacle #18	B5 / Good	Base of Foredunes	Kemp's ridley[5]	Unknown	N/A	N/A
13-May-08	1000	29.41068	-94.70012	East of Trash Receptacle #21	B6 / Fair	N/A (false crawl)	Kemp's ridley[6]	Unknown	N/A	N/A
14-May-08	0800	29.39883	-94.71208	West of Trash Receptacle #12	B4 / Good	Foredune Depression	Kemp's ridley[5]	Unknown	N/A	N/A
30-May-08	0810	29.39587	-94.71395	Adjacent to Trash Receptacle #10	B4 / Good	Foredune Depression	Kemp's ridley[5]	Unknown	N/A	N/A
30-May-08	0826	29.40865	-94.70257	~100 m (328 ft) West of Magnolia Drive	B6 / Fair	Upslope of First Foredune	Kemp's ridley[5]	Unknown	N/A	N/A
9-Jun-08	0930	29.44850	-94.63907	~15 m (49.2 ft) East of Trash Receptacle #56	B13 / Good	N/A (false crawl)	Unknown	Unknown	N/A	N/A
24-Jun-08	1002	29.51157	-94.48805	1 km (0.6 mi) East of Rollover Pass	B33 / Poor	Base of Foredunes	Loggerhead[5]	Wild[7]	N/A	N/A
16-Jul-08[2]	2250	29.44185	-94.65213	Emerald Beach #1 Housing Development: Surfview Road Beach Access	B12 / Fair	Foredune Depression	Kemp's ridley[5]	Unknown	N/A	N/A
25-Jul-08[2]	0944	29.45877	-94.61750	West of Trash Receptacle #69	B16 / Good	Base of Foredunes	Kemp's ridley[5]	Unknown	N/A	N/A

[1] Straight carapace length (notch-tip).

[2] Date biologists documented nest hatching; actual nesting date unknown.

[3] Geographic coordinates estimated based on nest site description.

[4] Nesting female identified by biologists.

[5] Nesting female not seen; species identity based on hatchlings (D. Shaver, NPS, pers. comm.)

[6] Female not seen; species identity based on width of crawl.

[7] Headstart program exclusive to Kemp's ridleys.

Figure 1. Characterization of Sea Turtle Nesting Habitat Quality on the Western Segment (Sections 1-12) of Bolivar Peninsula, Texas.

Figure 2. Characterization of Sea Turtle Nesting Habitat Quality on the Central Segment (Sections 13-29) of Bolivar Peninsula, Texas.

[1] Table 1 specifies section attributes used in quality determinations.

Image Houston-Galveston Area Council
Image © 2009 DigitalGlobe
Data U.S. Navy
Image © 2009 TerraMetrics

Figure 3. Characterization of Sea Turtle Nesting Habitat Quality on the Eastern Segment (Sections 30-42) of Bolivar Peninsula, Texas.

Figure 5. Historical Nest Locations vs. Current Nesting Habitat Quality within the Western Segment (Sections 1-12) of Bolivar Peninsula, Texas.

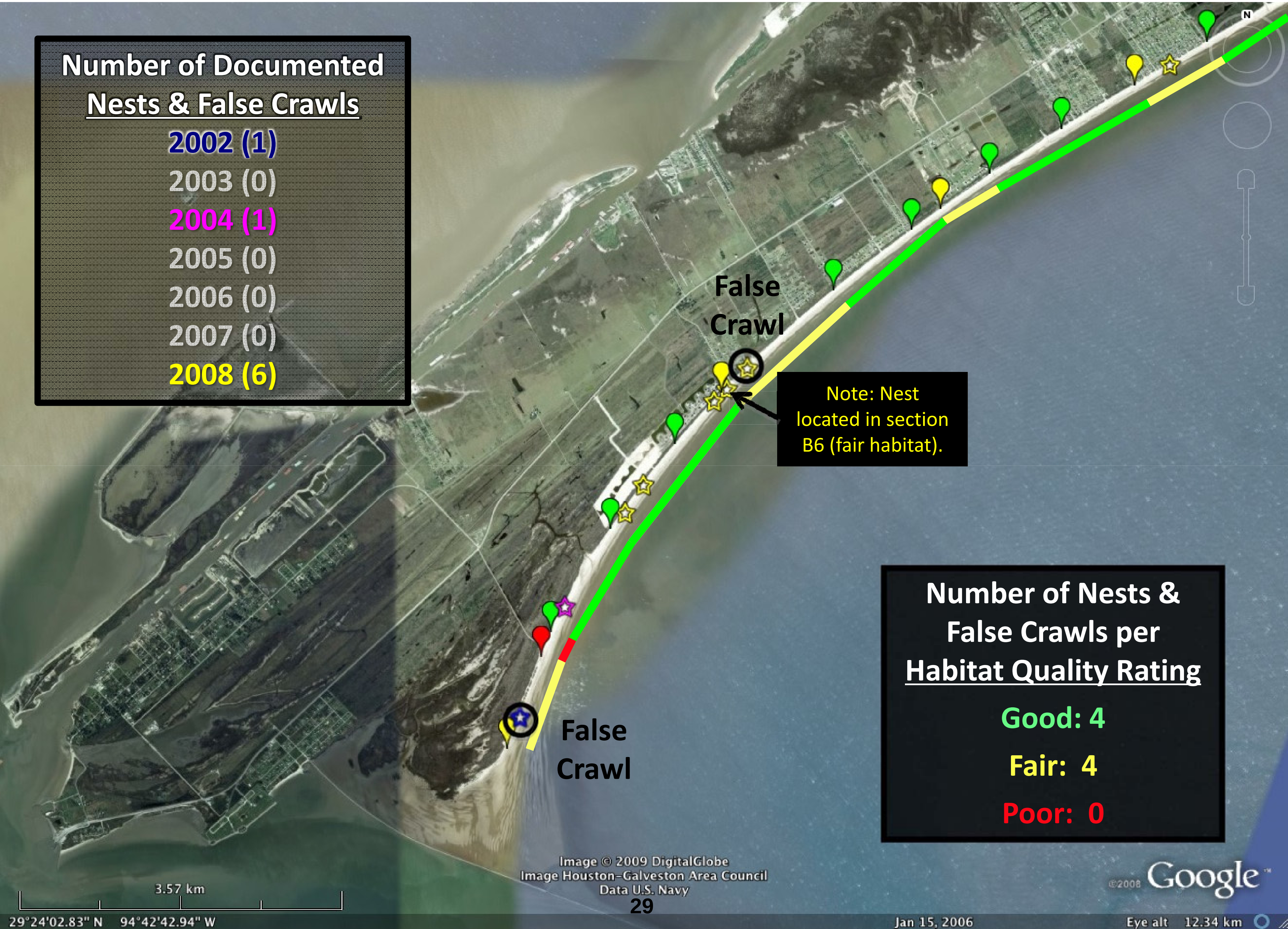

Figure 6. Historical Nest Locations vs. Current Nesting Habitat Quality within the Central Segment (Sections 13-29) of Bolivar Peninsula, Texas.

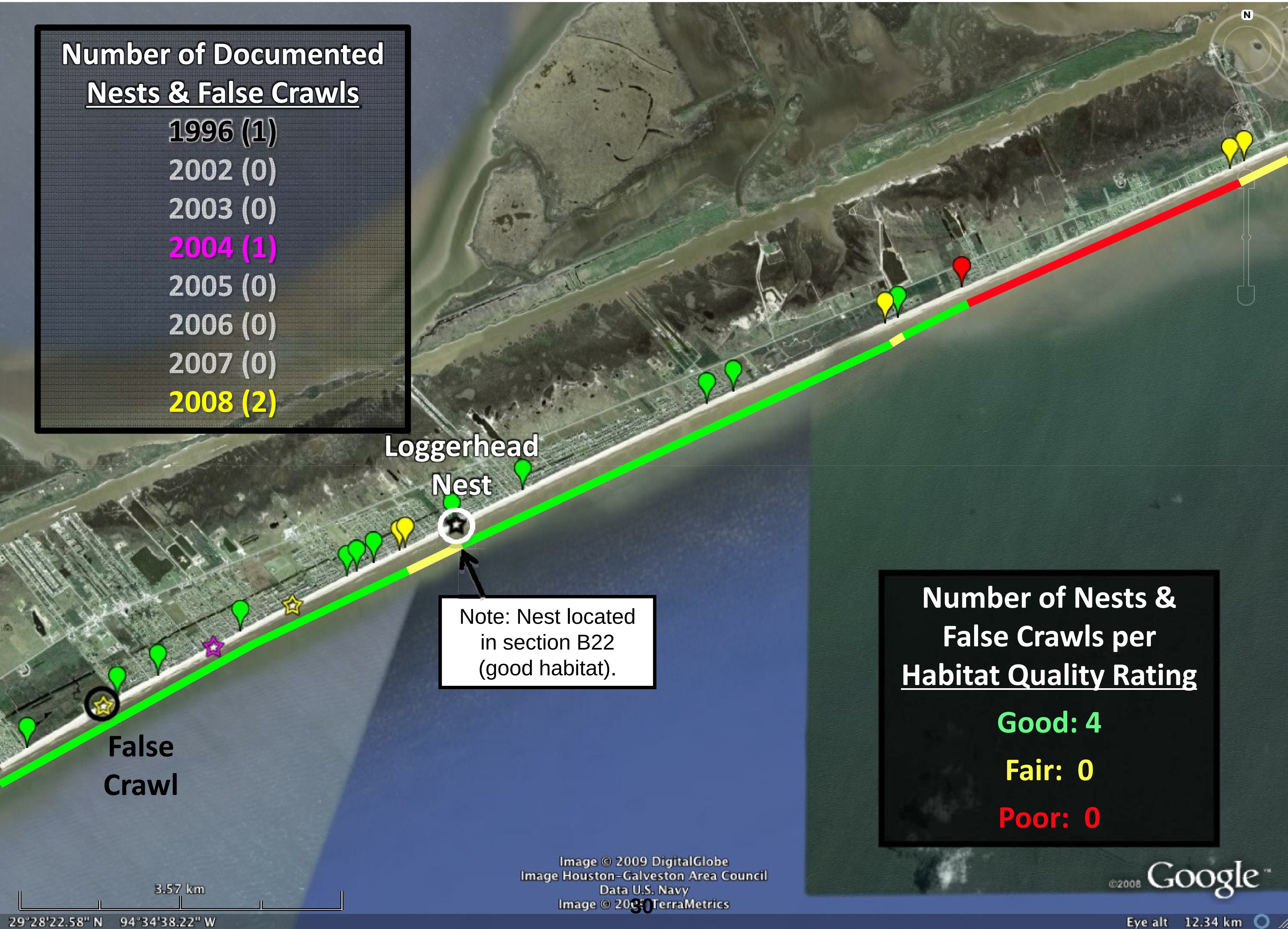

Figure 7. Historical Nest Locations vs. Current Nesting Habitat Quality within the Eastern Segment (Sections 30-42) of Bolivar Peninsula, Texas.

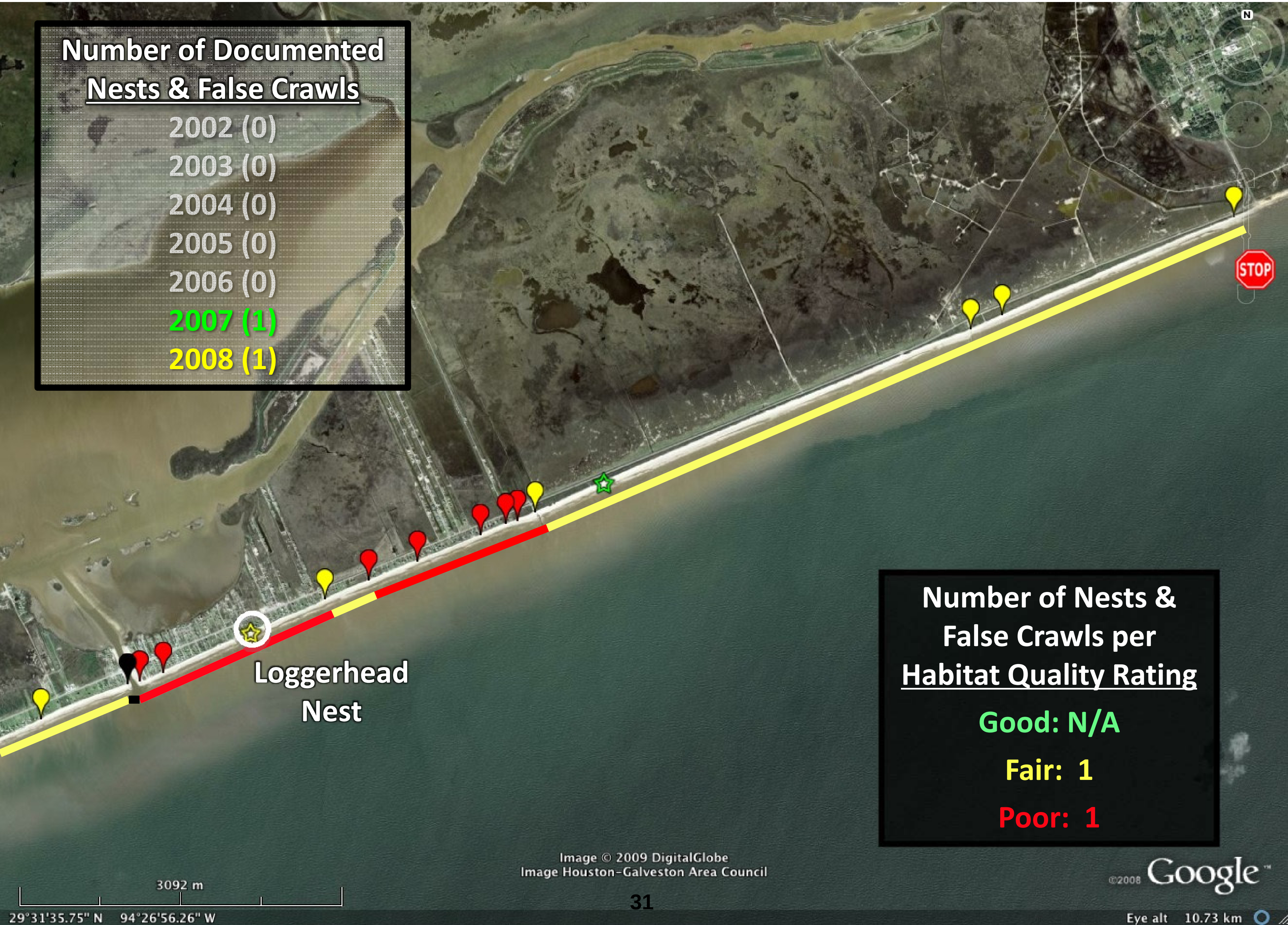

Figure 8. Nest site selected by loggerhead turtle (*Caretta caretta*) in section B33 (poor habitat) on Bolivar Peninsula on 24 June 2008. (Photos by Mark Bane.)

Figure 8.1. Nest site habitat characterized by geotube resembling natural dune and lack of development.

Figure 8.2. Habitat immediately west of nest site characterized by residential development fronted by partially exposed geotube.

Figure 8.3. Habitat immediately east of nest site characterized by residential development fronted by exposed, unvegetated geotube.

Figure 9. Site of non-nesting emergence by Kemp's ridley sea turtle (*Lepidochelys kempii*) potentially caused by water pooled above high tide line in section B6 (fair habitat) on Bolivar Peninsula on 13 May 2008. (Photo by Christi Hughes.)

Incoming and outgoing tracks (identified by arrows) do not appear above pooled freshwater from terrestrial source.