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Temporal shift of sea turtle nest sites in an eroding barrier island beach

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ABSTRACT

Shoreline changes affect functionality of a sandy beach as a wildlife habitat and coastal erosion is among the primary causes of the changes. We examined temporal shifts in locations where loggerheads placed nests in relation to coastal erosion along a barrier island beach in the northern Gulf of Mexico. We first confirmed consistency in long-term (1855–2001), short-term (1976–2001), and more recent (2002–2012) shoreline change rates in two adjacent beach sections, one historically eroding (west beach) and the other accreting (east beach). The mean annual shoreline change rate in the two sections was significantly different in all time periods. The recent (1998–2012) mean change rate was −10.9 ± 9.9 m/year in the west beach and −2.8 ± 4.9 m/year in the east beach, which resulted in the loss of about 70% and 30% of area in the west and east beaches, respectively. Loggerheads nested significantly closer to the vegetation line in 2012 than in 2002 in the west beach but the difference between the two time periods was not significant in the east beach. However, the distance from nests to the vegetation line from 2002 to 2014 was significantly reduced annually in both beaches; on average, loggerheads nested closer to the vegetation line by 9 m/year in the west beach and 5.8 m/year in the east beach. The observed shoreline change rate and corresponding shift of nest placement sites, combined with the forecasted future beach loss, highlighted the importance of addressing the issue of beach erosion to conserve sandy beach habitats.

1. Introduction

Sandy beaches provide critical habitat for a variety of wildlife species, thereby maintain high biodiversity. Conservation of sandy beach habitat is important but challenging because of the various natural and anthropogenic forces that alter the morphology and functionality of sandy beaches (Schlacher et al., 2006; Schooler et al., 2017). Coastal erosion is among the primary factors that influence shoreline and beach morphology. Severe beach erosion may reduce the area and change the condition of available habitat for coastal species and alter the abundance of infaunal organisms (Brown and McLachlan, 2002; Claudino-Sales et al., 2010; Zhang et al., 2005).

Sea turtles are circumglobally distributed species whose distribution and abundance is greatly influenced by availability and condition of sandy beaches. With their strong linkage to environmental conditions and degraded population status – of seven sea turtle species, six species are listed as vulnerable, endangered, or critically endangered on the IUCN Red list – there have been active research and conservation efforts to sustain the population of sea turtles (Hamann et al., 2010). Sea turtles spend most of their lives in the water, but they rely on sandy beaches for reproduction. Loss or narrowing of sandy beaches, also called “coastal squeeze” (Mazaris et al., 2008), could adversely affect sea turtle reproduction in several ways. First, the loss of nesting areas may increase density of nests in available beach areas, which may exceed the carrying capacity of the nesting beach (Mazaris et al., 2008). Loss of habitat may also result in fewer nests deposited. Second, erosion may create steeper slopes, making a given site less suitable for nesting in some beaches (Wood and Bjorndal, 2000; Maison et al., 2010). Third, the increased risk of saltwater inundation due to narrowed beach width could increase the risk of egg mortality and cause lower hatching success (Foley et al., 2006; Özdemir et al., 2008). Loss of sandy beaches caused by erosion has been evidenced in a number of sea turtle nesting beaches (Schlacher et al., 2006; Hawkes et al., 2009). An average annual decrease of 0.16 m beach width was observed in a high density loggerhead sea turtle (*Caretta caretta*) nesting beach along the Atlantic coast in the U.S. (Reece et al., 2013). In the Caribbean, 20% of historic nesting sites have been lost (McCleachan et al., 2006). Varied levels of erosion and partial shoreline reduction have been reported in a multiple sea turtle nesting beaches in Turkey (Kuleli et al., 2011).

Under the forecasted climate change, turtle nesting beaches may be

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negatively impacted by sea level rise and accelerated erosion caused by increased storm intensity which could lead to loss of beaches areas (Poloczanska et al., 2009; Hawkes et al., 2009). Furthermore, climate changes may affect ecological niches of species and thus their distributions (Mazaris et al., 2015). Increasing our knowledge on behavioral features in habitat selection and suitability for a species could greatly increase our conservation capacity.

Given that reduction of sandy beaches is predicted to further intensify in the coming decades (Brown and McLachlan, 2002), implementing beach management activities to protect biodiversity and maintain ecological processes is important (Ariza et al., 2008; James, 2000). Understanding how and to what extent shoreline change has been influencing sea turtle populations is essential in planning such management activities. In this study, we examine temporal changes in (1) the shoreline extent and (2) the spatial arrangements of loggerhead sea turtle nests in a historically eroding sea turtle nesting beach in a dynamic barrier island in northern Gulf of Mexico.

2. Methods

2.1. Study site

This study was conducted on 5.7 km (as of June 2013) of beach on Eglin Air Force Base property on Cape San Blas in Gulf County, Florida, USA (Fig. 1). The area represents the southern tip of the St. Joseph Peninsula, and is a part of the 2500 km coastline along the Gulf of Mexico that is made up of sandy beaches and barrier islands. Beaches in the northern Gulf of Mexico—the approximate southern limit of the temperate zone in the terrestrial domain of North America—historically serve as key habitats for a variety of wildlife species, including sea turtles (Godowin and Peterson, 2000). Our study beach supports one of the highest nesting densities of loggerhead sea turtles in the northern Gulf of Mexico. On average 43.4 loggerhead nests (8.7 nests/km) were placed annually in this beach, however a decline in nests has been observed between 1994 and 2010 (Lamont and Carthy, 2007; Lamont et al., 2012). The study beach is adjacent to the area predominated by mesic flatwoods and coastal scrub. There was neither major development nor landscape change along this beach during the study period.

Some portions of the St. Joseph Peninsula have historically experienced high rates of shoreline change (Orhan, 1992) and sediment transport (Stone and Stapor, 1996). In our study site, the cape spit, which is located approximately in the center of the study site, experiences one of the greatest rates of natural erosion in Florida (Lamont and Carthy, 2007, Fig. 1 B & C). This sand shoal extends approximately 15-km southward into the Gulf of Mexico and is in a near constant state of flux. During a three week period in the summer of 1994, the spit lost approximately 23 m of sand (Lamont and Carthy, 2007). The cape spit divides the study site into two distinct sections of beach, the western and eastern beaches that differ in bathymetry and current dynamics. The western portion (west beach) extends about 3 km to the northwest from the cape spit and is narrower and eroding, whereas the eastern portion (east beach), extends about 2.7 km from the cape spit and is wider and accreting (Lamont and Carthy, 2007). A previous study showed steeper slope on the eastern beach (−0.135) than in the west beach (−0.060; Lamont and Carthy, 2007).

2.2. Sea turtle nest survey

We used sea turtle nest survey data, including latitude/longitude of nest locations and identified species, from this study area gathered between 2002 and 2014 by the U.S. Geological Survey and University of Florida. Surveys were conducted each morning from May 1 to September 1 during the nesting season which continues until October 31. Surveyors walked along the beach, recorded GPS coordinates of nests (< 4.5 m accuracy) and identified the associated species by assessing features of track and nest, such as track width, track configuration, and body pit size, following the methods outlined by Pritchard et al. (1983). In this study, we focus on loggerhead, the primary nesting sea turtle species in this study beach, because nesting of other species, including green turtle (*Chelonia mydas*) and Kemp's ridley (*Lepidochelys kempii*), is rare.

2.3. Shoreline data and estimating erosion rates

Florida shoreline shapefile for 1998–2001, which was created based on the aerial images during this period, was obtained from the U.S. Geological Survey's National Assessment of Shoreline Change Web Mapping Application (http://coastal.er.usgs.gov/shoreline-change; accessed on March 3, 2016). More recent measures of the shoreline and the vegetation line bordering the beach were taken by a walking survey recording a series of GPS coordinates (< 15 m accuracy) at approximately every 10 s along the water line and vegetation in June 2012. The recorded coordinates were overlaid with the high-resolution orthorectified image (3 m) in 2013 (U.S. Geological Survey, Earth Resources

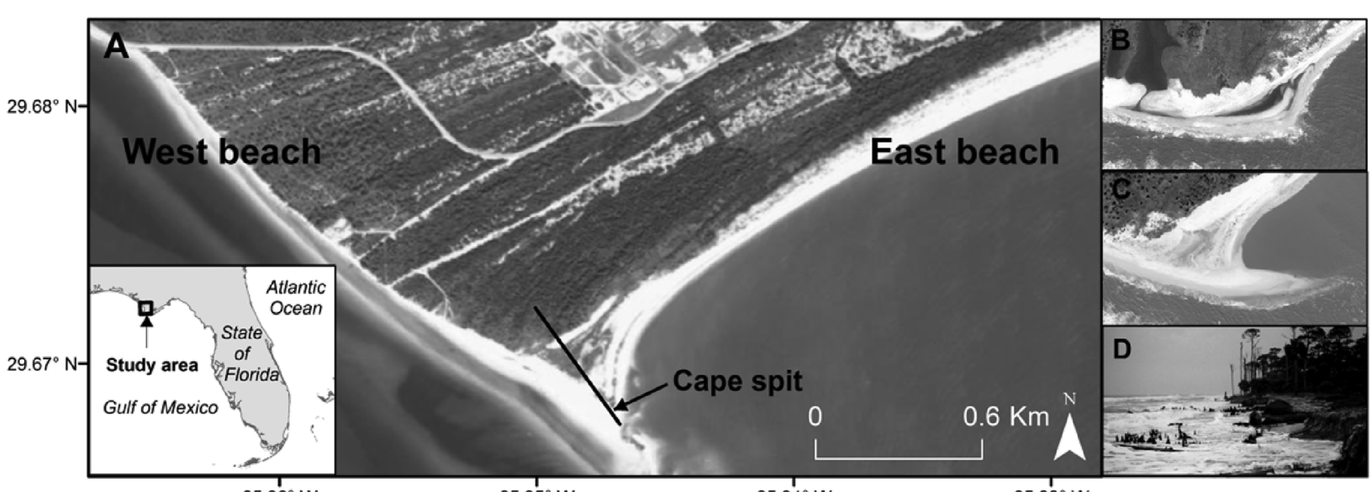

Fig. 1. (A) An aerial photo of Cape San Blas, which represents the southern tip of the St. Joseph Peninsula, Florida, in which the boundary (cape spit) of the east and west beaches in the study area is shown. The inset box shows the location of the study area within the state of Florida, USA. (B) Aerial images of cape spit in 2003 (Florida Department of Transportation, Aerial Photo Look-Up System, https://fdotewp1.dot.state.fl.us/aerialphotolookupsystem, accessed 31 May 2016) and 2013 (U.S. Geological Survey, Earth Resources Observation and Science Center, http://eros.usgs.gov/usa, accessed 31 May 2016). These images show server erosion and apparent shoreline change in the study beach. (D) An eroding portion of the west beach, located approximately 0.5 km west of the Cape spit, during a winter storm in January 2002.

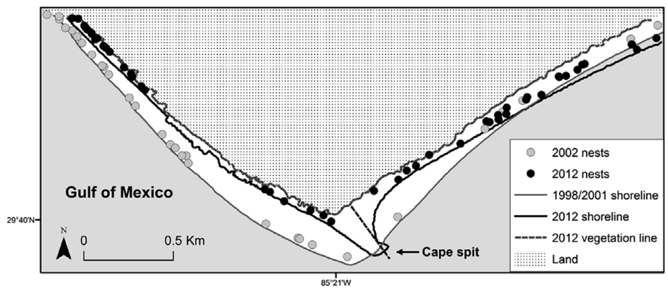

Fig. 2. Loggerhead nest locations during the 2002 and 2012 nesting seasons (May 1 – September 1), shorelines in 1998/2001 and 2012, and reference vegetation line in the study beach on Cape San Blas in Gulf County, Florida. The 1998/2001 shoreline was obtained from the U.S. Geological Survey's National Assessment of Shoreline Change Web Mapping Application (http://coastal.er.usgs.gov/shoreline-change; accessed on March 3, 2016). The 2012 shoreline and reference vegetation lines were created using GPS coordinates recorded on site in 2012.

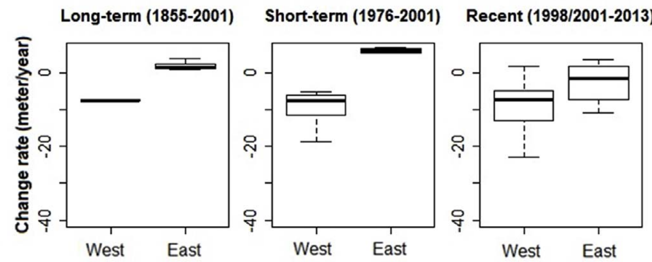

Fig. 3. Boxplots of long-term (1855–2001), short-term (1976–2001), and recent (1998/2001–2012) annual shoreline change rates in meter along the west and east beaches on Cape San Blas in Gulf County, Florida.

Observation and Science Center, http://eros.usgs.gov/usa, accessed 31 May 2016; Fig. 1 C) to delineate the water lines and vegetation line using ArcGIS 10.3. We used this digitized vegetation line as a reference line for all years because data to delineate an accurate historical vegetation line were not available. The coordinates along the water line were taken during a low tide period to make conservative estimates of erosion.

To understand the historical pattern in shoreline change rates (change in meter per year) in two sections (east and west) of the study beach, we obtained shore-normal transects of the U.S. Geological Survey's National Assessment of Shoreline Change, which were placed at 50 m intervals within each beach section (Fig. 2) during the corresponding periods, long term (1855–2001) and short-term (1976–2001) (http://coastal.er.usgs.gov/shoreline-change; accessed on March 3, 2016; Morton and Miller, 2004a,b). The annual rate of shoreline change along the two beach sections was estimated for three periods: long-term (1855–2001), short-term (1976–2001), and recent (1998/2001–2012). The long-term and short-term estimates are mean change rates at all shoreline normal transects within each section. We used the same shore-normal transects to derive the recent change rate based on 1998/2001 and 2012 shorelines. Because exact year of the aerial data used to create the 1998/2001 shoreline was unknown, we used the maximum possible number of years (1998–2012) between the two shorelines to derive conservative estimates of the annual change rate. For each period (long-term, short-term, and recent), we compared estimated annual change rates along the west and east beaches with the Wilcoxon rank sum test using the SAS 10.3 NPAR1WAY procedure.

2.4. Analysis of nest sites

We analyzed the temporal changes in loggerhead nest locations in two ways. The first method was to compare the distance from each loggerhead nest to the vegetation line in 2002 and 2012, approximately the same period for which we estimated the recent shoreline change. This analysis was conducted with Wilcoxon rank sum tests using the SAS 10.3 NPAR1WAY procedure. The second method was a simple linear regression to estimate annual change in distance to the vegetation line from each nest. For each estimated regression line in east and west beaches, we tested whether the slope is significantly different from zero using *t*-test. The regression analysis was conducted with the SAS 10.3 GLM procedure. Both analyses were conducted separately for the west and east beaches because of the distinctly different shoreline change patterns found in the two sections.

3. Results

There was an apparent difference in the 1998/2001 and 2012 shorelines (Fig. 2). Overall, the shoreline had shifted toward the interior, except for portions of the beach near the cape spit and in the east end, where the beach width had actually increased by about 50 m. The amount of beach loss was dramatic, particularly in the west beach: the narrowest beach width based on the 1998/2001 shoreline was about 55 m (near the northwestern end), whereas the narrowest beach width based on the 2012 shoreline was only about 8 m (around the middle of the west beach, Fig. 2). The beach is generally wider in the eastern section than in the western section, and the shortest width based on the 2012 shoreline in the eastern section was about 30 m.

This observed recent shoreline change pattern—that is, a greater amount of erosion in the west beach and some accretion in the east beach—is concordant with the long-term and short-term change pattern (Fig. 3). The mean change rates for long-term, short-term, and recent years were -6.22 ± 3.74 m, -9.16 ± 4.09 m, and -10.93 ± 9.87 m in the west beach and 1.70 ± 0.87 m, 5.02 ± 2.69 m, and -2.79 ± 4.88 m per year in the east beach. Based on the Wilcoxon rank sum test, the difference in the change rate at the normal transects in both beach sections was significant in all three time periods ($p < .01$ for all periods).

Based on the area calculated by 1998/2001 and 2012 shorelines and the reference vegetation line, the sandy beach area was reduced by 70% from 32.2 ha to 9.6 ha in the west beach and by 30% from 24.5 ha to 17.1 ha in the east beach. During the approximately corresponding period, from 2002 to 2012, nest locations tended to shift toward the vegetation line (Fig. 2). The magnitude of the shift was larger along the west beach, where greater beach erosion occurred than along the east beach. Along the west beach, the mean distance between nests and the vegetation lines was 110.0 ± 50.1 m in 2002 and 10.5 ± 10.0 m in 2012, and this difference was significant (Wilcoxon test statistics = 900, $p < .01$). The difference between 2002 (mean = 76.2 ± 59.6 m) and 2012 (mean = 53.1 ± 25.3 m) was not significant along the east beach (Wilcoxon test statistics = 112, $p > .05$, Fig. 4A) where the mean distance was 76.2 ± 59.6 m in 2002 and 42.5 ± 27.3 m in 2012. Although the measured nest locations are susceptible to GPS errors (< 4.5 m), overall the mean distance from nests to the vegetation line is much greater than the location errors. Therefore, we assume that the effect of GPS accuracy in the analysis is relatively minor.

The distance from the nests to the vegetation line significantly declined annually from 2002 to 2014 along both west and east beaches (Fig. 4B). Based on the estimated coefficients of the regression slope (shown in Fig. 4B), the distance was reduced by 5.77 ± 0.71 m ($t = -8.09$, $p < .01$ for the test of the significance of the slope) annually along the east beach. The estimated annual reduction was 9.04 ± 0.52 m ($t = -17.36$, $p < .01$ for the test of the significance of the slope) along the west beach.

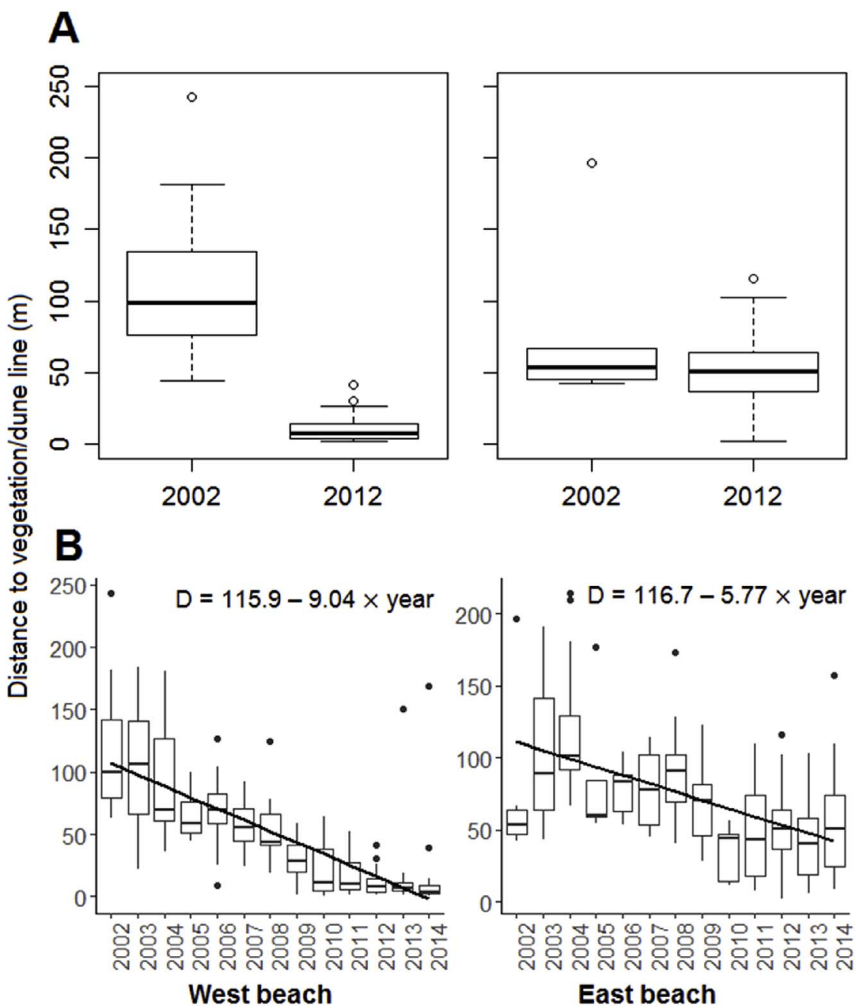

Fig. 4. (A) Box plots of the distance from loggerhead nests to the vegetation line in 2002 and 2012 and (B) scatter plots with regression lines of year (number of year with 2002 being year 1) vs. distance from the loggerhead nests to the vegetation/dune line (D, in meter) from 2002 to 2014 along east and west beaches in the study area on Cape San Blas in Gulf County, Florida.

4. Discussion

4.1. Shoreline changes and nest site selection of loggerheads

This study illuminated steady beach losses for a long period, from mid 1800s to present, and the corresponding changes in nest site selection of loggerhead sea turtles in the study area, Cape San Blas beach in St. Joseph Peninsula in northern Gulf of Mexico. Despite the different sources of data used to estimate shoreline change in each time period, the observed patterns were consistent in both beach sections. As a part of a barrier island system, the Peninsula historically experiences a high rate of erosion (Orhan, 1992; Stone and Stapor, 1996). Using recently delineated shoreline data, we confirmed that the erosion has occurred continuously at comparable rate and pattern, that is, the greater rate of shoreline change in the west beach than in the east beach (Stone and Stapor, 1996). This distinctly different shoreline change pattern is due to eastward shoal movement which erodes on its western beach and accretes on the east beach by transporting sands (Orhan, 1992).

In response to the beach loss, loggerheads selected nesting sites closer to the vegetation line at similar rate (9 m/year on the west beach and 5.7 m/year on the east beach) over time. These results raise concerns about further erosion and the sustainability of the ecosystem for sea turtle nesting in this area. Currently, the west beach is considerably narrower than in previous years, indicating habitat loss for the nesting turtles. The reduction of beach width has also led turtles to nest closer to the water line, which increases the risk for overwash and inundation of nests. As a result of the beach erosion, turtles have nested progressively closer to the vegetation, which could increase predation risk (e.g. increased predation of hawksbill eggs by Asian mongoose *Herpestes javanicus* in vegetation zone was reported by Leighton et al., 2008), create obstructions (such as plant roots) to affect nest construction and to cause hatchling disorientation, and increase disturbances to embryonic development by plant roots (Bustard and Greenham, 1968; Whitmore and Dutton, 1985; Conrad et al., 2011). Nesting close to the vegetation zone could also affect the sex ratio of the hatchlings; the shadow of the elements backing the beach could lead to lower temperatures at the nests and thus could alter female skewed hatchling sex-ratios. Given the operational sex ratio of sea turtles could counterbalance the female biased sex ratio (Hays et al., 2014) and that more females could potentially reproduce (Hays et al., 2017), this shift to the upper zones of the beaches is likely to have an impact upon future population recruitment.

We previously found steep declines in the number of loggerhead nests on our study beach from 1994 to 2010 (Lamont et al., 2012); however, because a declining trend in abundance of loggerhead nests was observed statewide during this period and was attributed to a variety of other threats (Witherington et al., 2009), we are unsure whether beach loss was a major cause of the decline in our study site. Comparing the trends in nest abundance and emergence success—as well as other reproductive parameters, such as nest failure, predation rate, and sex ratios—along the two distinctly different beach sections in our site and re-distributions of nests along the peninsula would provide further understanding about the impacts of shoreline change on sea turtle reproduction.

Impending global climate change and the associated sea level rise and increased frequency of tropical cyclones threaten to cause future

loss of sandy beach areas (see Woodruff et al., 2012 for review). Shoreline changes resulting from climate change may increase the risk of habitat loss for various threatened and endangered species, including sea turtles (Daniels et al., 1993; Fish et al., 2005; Pike et al., 2015). Through a study of the Caribbean island of Bonaire, Fish et al. (2005) found that habitat vulnerability to rising sea levels is determined by the physical characteristics of a given site; in general, narrow and low-elevation beaches are at a greater risk of habitat loss (Fish et al., 2005). These results are concordant with the observed vulnerability of coastal barrier islands—which comprise small islands and peninsulas with offshore deposits separate from the coastline—to sea level rise and increases in the frequency and intensity of oceanic storms (Feagin et al., 2010). Because of limited supplies of new sand, rising sea levels are predicted to cause erosion and a transgression in barrier coasts (Curray, 1964; FitzGerald et al., 2004). Barrier island chains, which have high social value for recreation and storm protection, are recognized as a finite natural resource facing uncertain futures (Pilkey, 2003). A number of coastal barrier islands and sandy beaches along the Gulf of Mexico and Atlantic coasts, including our study area, are important sea turtle nesting habitats and are designated as protected areas. By showing the large extent of the shoreline change and the corresponding shifts of loggerhead nest locations, our study demonstrated one way in which shoreline change has altered the critical ecosystem services of a barrier island, as discussed by Feagin et al. (2010).

4.2. Solutions to coastal erosion and beach loss

Availability of secured nesting and foraging habitat is important to sustain wildlife populations, and it is critical for imperiled species such as sea turtles. Several restoration and conservation activities have been practiced locally to address the problem of beach loss, but currently there is no perfect single solution to this problem. Beach nourishment is one management option to restore eroding sandy beaches. Beach nourishment has the potential to increase available sea turtle nesting habitat (Crain et al., 1995); however, negative impacts from nourishment have also been documented. Rumbold et al. (2001) reported significant declines in nest abundance and corresponding increases in false crawl abundance in Palm Beach County, Florida in the two years immediately following nourishment of that nesting beach. In the Archie Carr National Wildlife Refuge, Florida, over 50% decrease in nesting success was observed for green and loggerhead turtles post-nourishment within the Refuge, along with a decrease in reproductive output (Brock et al., 2009).

When nest inundation is a particular concern, relocation of sea turtle nests is sometimes conducted as a species specific conservation activity. Several studies have indicated that relocation of sea turtle nests could be an effective method for saving eggs without damaging embryonic development, but nests must be relocated within 12 h of deposition to avoid damaging respiratory membranes (Ahles and Milton, 2016; Tuttle and Rostal, 2010). Also, selection of relocation sites may influence hatching success and sex determination (Spanier, 2010; Tuttle and Rostal, 2010).

Whereas coastal erosion is a common issue in shorelines around the world (Bird, 1985), the problem can be highly nuanced on a local scale, as seen in our findings of greater variability in shoreline change rate within a relatively short study beach. In planning conservation activities, one important step is to prioritize beaches with both high ecological value and high erosion rates in a larger and local scale to ensure the effectiveness. To this end, historical shoreline change maps such as those used in this study—which were produced by the National Assessment of Shoreline Change Project (http://coastal.er.usgs.gov/shoreline-change)—could provide data to help understanding the degree of shoreline change at large and small scales to support such efforts. Although our study is limited to showing effects of shoreline change on nesting loggerheads in a relatively small beach, a further study which covers a greater extent of the loggerhead nesting beaches would provide a clearer picture of the threat shoreline change and beach loss pose to the population of this species. A recent study emphasized a need to improve our understanding on global population trend and conservation success of sea turtles to apply more efficient management and conservation measures (Mazaris et al., 2017). Given the global conservation interest for sea turtle species (Wallace et al., 2011), a study, that combines a large-scale modeling to predict range shift under forecasted climate change (Almpanidou et al., 2016) and identification of conservation hotspots based on coastal changes and nest density (Fuentes et al., 2016) could fill in information gaps by delineating the area for conservation of the species (Mazaris et al., 2014). Also, implications of this study could be extended to other sea turtle species as well as other species which use sandy beaches such as shorebirds.

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