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A Literature Review of Beach Nourishment Impacts on Marine Turtles

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Abstract

This report was developed by the US Army Engineer Research and Development Center-Environmental Laboratory (ERDC-EL) to summarize the known impacts to nesting sea turtles along the Atlantic and Gulf Coasts resulting from beach nourishment. The US Army Corps of Engineers (USACE) is responsible for maintaining the nation's infrastructure to include ports and harbors through dredging of Federal navigation channels as well as shoreline stabilization. Shoreline stabilization through beach nourishment activities can provide opportunities for reductions in storm surge, flood control, and provide opportunities for residential growth, recreational activities, and coastal habitat restoration (Guilfoyle et al. 2019). Beach nourishment is an effective method for protection and enhancement of coastal development projects but may have detrimental impacts on marine life (e.g., nesting sea turtles and shorebirds). The objective of this report is to examine all elements of the beach nourishment process including active beach construction, entrainment of marine turtles in hopper dredges, beach protection and hard structures, beach profile features, compaction and shear resistance, artificial lighting, marine turtle nest relocation, and nesting habitat factors. Recommendations for mitigating and minimizing these impacts are provided.

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Preface

This study was conducted by the US Army Corps of Engineers (USACE), US Army Engineer Research and Development Center (ERDC), Vicksburg, MS. Funding was provided through the Ecosystem Management and Restoration Research Program (EMRRP), Project number 485296.

The work was performed by the Coastal Wetland and Ecological Resources Branches, of the Ecosystem Evaluation and Engineering Division, ERDC-Environmental Laboratory (ERDC-EL). At the time of publication, Ms. Patricia Tolley was the Chief, Wetland and Coastal Ecology Branch; Dr. Harley McAlexander was the Acting Chief, Ecological Resources Branch; Mr. Mark Farr was Chief, Ecosystem Evaluation and Engineering Division; and Dr. Jennifer Seiter was the Technical Director. The Deputy Director of ERDC-EL was Dr. Brandon Lafferty, and the Director was Dr. Edmund Russo.

This work represents a thorough literature review and detailed assessment on the known impacts of USACE beach nourishment operations on nesting marine turtles along the Atlantic and Gulf Coasts. Ms. Dene Dickerson, Mr. Craig Theriot, and Drs. Doug Clarke (retired ERDC-EL employee) and Michael P. Guilfoyle, ERDC-EL, provided internal reviews.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

Executive Summary

This study compiled current scientific and government literature to provide an understanding of the known impacts of beach nourishment on nesting marine turtles, with focus on the Atlantic and Gulf Coasts in the Southeastern United States. Impacts of beach nourishment are discussed in terms of the active construction site, entrainment, equipment and beach construction, artificial lighting, nest relocation actions, nesting habitat factors, beach protection and hard structures, sand compaction and shear resistance, beach fill material, beach profile (width/slope/elevation), escarpments, nest chamber geometry, nest concealment, beach tilling, nest microhabitat requirements, sediment moisture content, respiratory gas diffusion, and nest temperature effects.

Negative impacts on marine turtles are documented by entrainment in hopper dredges, the determent of nesting and access to beaches from construction activities, including beach armoring and hard structures, and the disorientation of turtles from artificial lighting. Moreover, beach nourishment can have negative impacts by increasing sand compaction and beach shear resistance and reducing access to beaches from escarpment formation. Relocating active marine turtle nests is an option that may be employed to protect them from predicted severe storms, ongoing beach nourishment, or other planned coastal engineering and construction actions. However, this action often results in significant declines in hatchling success. The importance of nest chamber geometry and nest microhabitat features are discussed in terms of potential negative impacts on these features during beach nourishment operations.

A series of actions are recommended to minimize or mitigate potentially negative impacts of beach nourishment on nesting marine turtles. Such actions include implementing the Corps' Programmatic Biological Opinion for the protection of nesting sea turtles, preventing dredged material deposition during peak sea turtle nesting periods, use of quality sand suitable for turtle nesting, removing all derelict or other debris from beach, using beach profile attributes that closely mimic original beach profile, or use of beach profiles palatable for nesting turtles. Additional recommendations include approaches to survey nesting turtles pre- and post-project using surveyors authorized by the Florida Fish and Game Commission. Sand compaction should also be monitored, and beach tilling may be prescribed if beach is determined to be too compacted.

Escarpments should also be monitored and leveling of the beach may be necessary if such formations block access to the beach for nesting sea turtles. Finally, artificial lighting should be designed to direct light sources away from angles that could disorient nesting turtles, and vegetation plantings need to be designed and implemented to maintain access to nesting sites.

Significant progress has been made in designing and implementing beach nourishment projects to minimize negative impacts on nesting sea turtles. These issues are discussed in detail and recommendations are summarized. This report should help inform the USACE coastal engineers and natural resource managers on the best approaches to protect our threatened and endangered sea turtle species utilizing beach-nesting habitats in the Southeastern United States.

1 Introduction

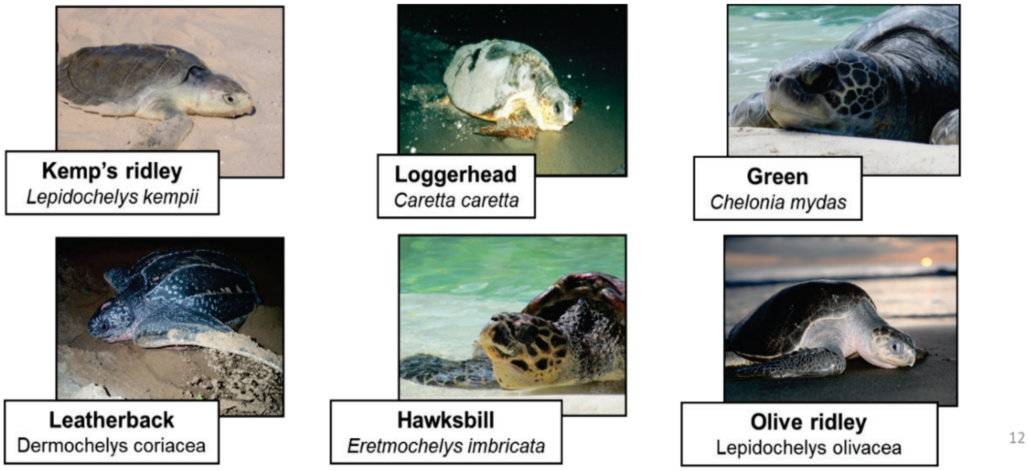
1.1 Background

Severe storms and sea level rise continue to erode coastal shorelines. Since 1950, over 100 named hurricanes have made landfall on the eastern seaboard and Gulf Coast of the United States (National and Oceanic Atmospheric Administration [NOAA] 2019). Of these, 12 were category four or higher at the time of landfall. This total does not include storms that passed close enough to the coast to cause beach erosion but did not make landfall. Beach erosion impacts can be mitigated by an inland retreat of coastal development, coastal armoring with hard structures (i.e., seawalls or rock revetments), and/or soft stabilization with sand-placement projects, also known as beach nourishment. Due to resistance to coastal retreat, potential exacerbation of erosion issues by hard structures, and the economic value of beaches, engineered sand placement projects (e.g., beach restoration, beach nourishment, and inlet sand bypassing) are currently in high demand to repair hurricane ravaged beaches. These activities are typically considered temporary solutions since they cannot alter the near shore forces causing erosion. However, these projects have increased along the Atlantic and Gulf coasts in both number and size of projects (Trembanis et al. 1999) as they are increasingly being chosen as a means to combat sea level rise and related beach erosion problems (Klein et al. 2001).

The National Research Council (NRC) concluded that beach nourishment is a viable engineering alternative and the preferred method for both shore protection and beach restoration and has demonstrated effective protection from coastal storms and flood damage (NRC 1995). The first documented beach nourishment project occurred at Coney Island in 1922 (Farley 1923). In 1962, the first congressionally authorized beach nourishment project was undertaken by the US Army Corps of Engineers (USACE) after a severe storm damaged beaches from Florida to New England. By 1987, over 400 miles of US shoreline had undergone beach nourishment, using at least 400 million yd^3 of sand in the process (Pilkey and Dixon 1996; Pilkey 1999). In Florida, where extensive sea turtle nesting occurs, the Florida Department of Environmental Protection (FDEP) has designated 421 of the 825 miles (Clarke 1993) of sandy shoreline as critically eroded (FDEP 2019). Of the 35 coastal counties, all but one (Jefferson), have either eroding or critically eroding beaches (FDEP 2019). As a result, the USACE Jacksonville District was involved in over 150 shore protection projects in 18 counties (USACE 2010). Sand replenishment projects in Florida have doubled or nearly doubled every decade since 1980 (Lott et al. 2009).

While beach nourishment projects have been conducted since the 1920s, the issue received little attention until the passage of the Endangered Species Act (ESA) of 1973. The ESA provided legal protection to sea turtles and other species resulting in numerous monitoring programs designed to evaluate the potential environmental impacts of beach nourishment projects. All five species of sea turtles occurring in the US are listed as threatened or endangered under the ESA (Figure 1-1). Endangered status means a species is considered in danger of extinction throughout all or a significant portion of its range; threatened means it is likely to become endangered. Loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and leatherback (*Dermochelys coriacea*) turtles regularly nest on beaches within the US, and all depend upon US coastal waters for foraging and migratory habitat (Figure 1-1). The Kemp's ridley (*Lepidochelys kempi*) and Hawksbill (*Eretmochelys imbricata*) occasionally nest in the US (Figure 1-1) but are dependent on the shallow coastal habitat of the US east coast and the Gulf of Mexico for foraging and developmental habitat. The most common sea turtle nesting in the US is the loggerhead followed by green and leatherback turtles. Most sea turtles nesting within the US do so in Florida, Georgia, South Carolina, and North Carolina, although sporadic nesting occurrences have been reported from Texas to Alabama and Virginia to New Jersey (Spotila 2004).

Figure 1-1. Sea turtle species known to nest along the coast of the Southeastern United States. Photo credit: USACE: ERDC.



Beach nourishment not only provides increased beach width for shore protection but also may provide increased "real estate" of sea turtle nesting habitats that would otherwise be unavailable due to erosion. However, nourished beaches may not increase available habitat if the quality necessary for successful nesting and hatching is compromised. Changes to natural beach characteristics may adversely impact nest site selection, digging behavior, clutch viability, and hatchling emergence. In addition, accidental injury or death (incidental take) can occur to turtles when entrained by hopper dredges during a nourishment project. Therefore, it is critical to identify the beach habitat characteristics necessary for successful sea turtle nesting and consistently construct suitable habitats during beach nourishment projects. Owing to declining sea turtle populations and the prevalence of beach nourishment projects, it is critical to understand the physical and biological factors necessary for suitable sea turtle nesting habitats. These factors will be reviewed below.

1.2 Objectives

The objectives of this effort are listed below.

1. A thorough literature review on the status of our understanding of the impacts of beach nourishment on nesting marine turtles along the Atlantic and Gulf Coasts in the Southeastern United States.
2. Thoroughly cover a wide-range of important issues concerning beach nourishment impacts including active construction hazards, entrainment, equipment and beach construction, artificial lighting, nest relocation,

nesting beach habitat features, beach protection with hard structures, compaction and shear resistance, beach fill material, beach profile (width/slope/elevation), escarpments, nest chamber geometry, nest concealment, beach tilling, nest microhabitat requirements, sediment moisture content, respiratory gas diffusion, and nest temperature.

3. Provide a series of recommendations to minimize or mitigate these negative impacts to improve the outcome for nesting marine turtles.

1.3 Approach

To synthesize and expand our current understanding of impacts to nesting sea turtle due to beach nourishment on the Atlantic and Gulf Coasts in the Southeastern United States, a thorough literature review was performed.

These impacts are discussed in detail and cover all topics mentioned. A series of recommendations that should be implemented by the USACE to minimize negative impacts of beach nourishment on nesting sea turtles on the Atlantic and Gulf Coasts are also provided.

1.4 Scope

This report targets USACE coastal engineers and land managers managing or regulating coastal engineering projects that potentially impact nesting marine turtles. However, the results of this effort may be of significant interest to all biologists and land managers interested in beach habitat creation or restoration to benefit nesting marine turtles. This information should be considered for monitoring and assessing beach nourishment impacts on marine turtles for USACE project lands or coastal engineering operations. It could also benefit other state or Federal land managers, or private landowners who have an interest or objective to manage coastal lands for nesting populations of our threatened and endangered marine turtles.

2 Beach Nourishment Impacts

2.1 Active construction hazards

Generally, sea turtle nesting activity in the US ranges from May through August (peak June through July) but may occur from March through October due to regional and species variations (Spotila 2004). Since incubation requires 6-13 weeks (dependent on nest temperature), it is possible for some eggs to hatch as late as October or November. Nourishment projects conducted during the nesting season may deter nesting attempts and cause incidental takes (mortalities) of sea turtles (adults, hatchlings, or eggs) from increased human activity, equipment hazards, obstruction on the beach, and increased lighting (Crain et al. 1995).

2.2 Entrainment

Many beach nourishment projects involve the use of hopper dredges to mine offshore sand (Figure 2-1). Occasionally, adult and sub-adult sea turtles are killed or injured when entrained by hopper dredges. Entrainments have only been documented during hopper trailing suction-type dredging. Dickerson et al. (2004) reviews the impacts of dredging on sea turtles. The Bureau of Ocean Energy Management (BOEM) estimates the “take” rate is one turtle per 3.8 million yd^3 of dredged sand (Michel et al. 2013). Incidental takes of sea turtles can be found by region on the USACE Sea Turtle data base at https://dqm.usace.army.mil/odess/#/home. To minimize sea turtle takes, hopper dredges must comply and follow all recommendations in the National Marine Fisheries Service (NMFS) Biological Opinion issued for each state. The sea turtle deflecting draghead (Figure 2-2) is required for all hopper dredging projects during months that turtles may be present, unless a waiver is granted after consultation with the NMFS. Additional information on the development and evaluation of the sea turtle deflecting hopper dredge draghead can be found in Banks and Alexander (1994). The Statewide Programmatic Biological Opinion (USACE 2011) requires 100% sea turtle observer coverage, particularity during hopper dredging activities in southeast Florida and 100% overflow screening to document incidental takes. Accurate record keeping of any sea turtle injuries or deaths during hopper dredging activities must be kept and submitted to the NMFS and US Fish and Wildlife Service (USFWS).

Figure 2-1. Example of a hopper trailing suction-type dredge. Photo credit: USACE-ERDC

Figure 2-2. A draghead of a hopper dredge with a sea turtle deflector. Photo credit: USACE-ERDC.

2.3 Equipment and beach construction

The use of heavy machinery on beaches during a construction project may have adverse effects on sea turtles. Equipment left on the nesting beach overnight can create barriers to nesting females emerging from the surf and crawling up the beach, causing a higher incidence of false crawls and unnecessary energy expenditure (USFWS 2015a). Operating motorized vehicles on the beach to complete the project work at night affects sea turtle nesting by interrupting or colliding with nesting turtles on the beach, headlights disorienting emergent hatchlings, vehicles running over hatchlings attempting to reach the ocean, and vehicle ruts on the beach interfering with hatchling crawling to the ocean (USFWS 2015a). Hatchlings become diverted, not because they cannot physically climb out of a rut (Hughes and Caine 1994), but because the sides of the track cast a shadow and the hatchlings lose their line of sight to the ocean horizon (Mann 1977). The additional time required to negotiate tire ruts may increase the susceptibility of hatchlings to dehydration and predation during migration to the ocean (Hosier et al. 1981). Driving over incubating egg clutches on the beach can cause mortality and sand compaction, which may reduce hatchling emergence success (Crain et al. 1995). Current guidelines in Florida, for example, state that staging areas for construction equipment shall be located off the beach during early and late portions of the nesting season for Brevard, Indian River, St. Lucie, and Broward Counties (before April 30 and after November 1), and peak nesting season (May 1 through October 31) for remaining counties (USFWS 2015a). Dates will vary for other states and regions.

To minimize impacts from equipment and construction activities, a staging site must be selected near the access point of the beach. This site will typically contain most of the materials needed for the construction and maintenance of the project such as dozers, loaders, cranes, dump trucks, light plant, and generators. In addition, there will be multiple sections of steel or High-Density Polyethylene (HDPE) pressurized dredged pipe ranging from 12 - 30 in. in diameter, depending on the size of the project (Figure 2-3). The mobilization process usually requires the use of heavy equipment to transport and connect pipe segments from the beach access point to the designated placement area. The placement of shore pipe is generally on the upper beach, away from existing dune vegetation, and just seaward of the toe of the primary dune. Once the pipe segments are connected, the use of heavy equipment is confined to the vicinity of the mean high-water line, away from dune vegetation on the upper beach. However, within the active placement area, heavy equipment is operating throughout the width of the beach to manage the outflow of sediment and to construct target elevations for the appropriate beach profile. Dredge pipes and construction equipment placed on the seaward side of the dune as well as deep ruts from heavy machinery can create physical barriers for female turtles attempting to nest and hatchlings moving towards the sea. To reduce impacts to sea turtles, pipe should be placed parallel to the shoreline and as far landward as possible so a significant portion of available nesting habitat can be utilized, nest placement is not subject to inundation or washout, and turtles do not become trapped landward of the pipe. Temporary storage of pipes and equipment will be located off the beach to the maximum extent possible (USACE 2015a).

Figure 2-3. Segment of pipeline and other equipment on a beach during beach nourishment. Photo credit: USACE: New York District.

The beach building process involves the use of bulldozers and sometimes backhoes to distribute the sediment as it falls out of suspension at the outflow end of the pipeline (Figure 2-4). Dikes are constructed on one or two sides of the effluent area to allow for extended settlement time of suspended solids in order to reduce turbidity levels in the nearshore environment. The construction zone, which includes the active disposal area and associated heavy equipment used to redistribute sediments, generally encompasses a fenced off area measuring 500 ft on each side of the discharge pipe. As sediment is deposited from the terminal end of the pipeline, dozers redistribute the sediment to a predetermined beach template consisting of marked stations along the length of the beach denoting the elevational requirements of the project. Once desired elevation is achieved, the pipe and heavy equipment are moved further down the beach. During all aspects of construction, vehicles and heavy equipment may transverse the beach; however, no equipment or activity is allowed within existing dune vegetation or other environmentally sensitive locations. These activities are summarized in the Statewide Programmatic Biological Assessment (2010).

Figure 2-4. Bulldozers moving sand creating the new beach profile. Photo credit: USACE: New York District.

2.4 Artificial lighting

Artificial lighting is known to have detrimental effects on the ecology of sea turtles, particularly for the hatchling stage when they emerge from nests on natal beaches and move towards the sea. Under natural conditions, sea turtles predominately hatch at night and show an innate and well-directed orientation to the water relying mostly on light cues attracting them towards the brighter horizon above the sea surface. Two main sources of artificial light are present during beach nourishment projects; lighting during nighttime construction activities and lighting associated with the dredge plant itself. While most construction work on these projects occurs during daylight, nighttime work may occur during a small construction window. A light management plan is required to be submitted and approved prior to pre-construction activities for projects where lighting is a concern for sea turtles and other sensitive organisms. Ample lighting can be obtained without affecting a large area through reduction shielding, lowering, and appropriate placement to avoid excessive illumination of the water's surface and nesting beach while meeting all Coast Guard, Corps EM-385-1, and Occupational Safety and Health Administration (OSHA) requirements. For Brevard and Broward Counties, avoidance and minimization of lighting the beach and nearshore waters, and upon offshore equipment is required before 30 April and after 1 November and during peak nesting season (May 1 through October 31) (USFWS 2015a). Dates may vary by region and state.

The disruptive effects of artificial lighting spilling onto the beach disorienting nesting females and impair the ability of hatchlings emerging from their nests to orient towards the sea has been documented by Verheijen (1985), Witherington (1989, 1990, 1991, 1992a, b, c), Witherington and Bjorndal (1991a, b), Salmon et al. (1995a, b), Salmon (2003, 2006), Witherington and Martin (1996, 2003), Bourgeois et al. (2009), Karnard et al. (2009), Witherington et al. (2014), and Kamrowski et al. (2014). Hatchlings rely almost exclusively on vision for orientation and brightness is a significant cue in the orientation process after hatching (Mrosovsky and Kingsmill 2010; Mrosovsky et al. 1979; Salmon et al. 1992; Limpus and Kamrowski 2013). This often results in a misdirected crawl inland towards the light source, where hatchlings may spend hours wandering the beach before finding the sea (Lorne and Salmon 2006), thereby reducing hatchling survival chances (Salmon 2006). Tuxbury and Salmon (2005) noted that hatchling sea turtles moved in a circular pattern with frequent changes in direction when artificial light is present, while Witherington and Martin (1996, 2003) found artificial lighting caused sea turtles to lose their direct sea-finding path causing hatchlings to expend extra energy wandering along the beach or death from exhaustion, dehydration, or predation.

Green turtles may be particularity sensitive to artificial lighting. Witherington et al. (2014) reported that during the initial phase of nesting, green turtles were deterred from nesting by people with small flashlights on the beach. Under natural conditions, sea turtle hatchlings emerge from their nest and immediately orient towards the ocean (Witherington et al. 1990). Hatchlings orient away from the elevated dunes and vegetation typically bordering the nesting beach. Sea turtles are very effective using visual cues to find the sea under natural lighting conditions, but this ability is greatly hampered from artificial lighting regardless of its source (Witherington and Martin 1996).

Mrosovsky and Kingsmill (2010) offers two theories on sea turtle sea-finding abilities; (1) a complex phototropotatic reaction to light initiates turning until sub-components of the system receive equal input, and (2) the direction of peak excitation is located instantaneously, and the turtles then head in that direction. Berry and Booth (2013) reported artificial lighting disrupted sea-finding behavior in loggerhead turtles on the Woongarra Coast in Queensland Australia because of coastal development, which tends to be associated with beaches frequently nourished. This study used crawling tracks of hatchlings that emerged from nests, as well as staged emergences, to assess the effect of lighting conditions at multiple beaches. Disrupted behavior was reported at some, but not all locations. At sites where orientation was disrupted, normal orientation was restored when a full moon was visible, presumably because lunar illumination reduced the perceived brightness of the artificial lights.

Weishampel et al. (2016) studied sea turtle nesting density in response to artificial lighting data (1992-2012) acquired by the Defense Meteorological Satellite Program (DMSP) and found that nest densities for all three sea turtle species were negatively influenced at neighborhood scales (< 100 km). However, only loggerhead and green turtles nest densities were influenced by artificial light at the individual beach scale (~ 1 km). The authors did note that although coastal urbanization increased in Florida during this time, nearly two-thirds of the surveyed beaches exhibited decreasing light levels (249 of 368 beaches). Thums et al. (2016) reported that artificial lighting affected the hatchling behavior of green turtles, with 88% of individual trajectories oriented towards the light, causing 23% more time spent in the nearshore environment. This can lead to increased mortality due to predation. Hatchlings typically transit quickly through the nearshore "hostile" zone by continuous swimming (up to 24 hr).

Light pollution disrupts the orientation and swimming behavior of hatchlings causing them to linger or become disoriented in the nearshore, leading to increased mortality with potential negative impacts on the population. Silva et al. (2017) found that artificial lighting reduced nesting attempts by 20% and increased the time turtles spent on the nesting process, forcing them to do more extensive beach crawls. Hu et al. (2018) found that the greater the light source, the lower nest density. The authors concluded that the light pollution influenced nest density in a descending order from green turtles to loggerheads and then to leatherbacks.

Newly nourished beaches tend to be wider and have a flatter beach berm exposing sea turtles and their nests to lights that were less visible, or not visible, from nesting areas before the sand placement activity occurred. Brock et al. (2007) reported a 600% increase in the number of loggerhead hatchlings disoriented on nourished beaches by artificial lighting over two years post-nourishment. Trindell et al. (2005) reviewed 10 yrs of beach nourishment projects and concluded that the number of sea turtles impacted by lights increases on the post-constructive berm. Disorientation increased by approximately 300% the first year after project construction and up to 542% the second year compared to pre-nourishment reports. Since 1987, approximately 8,700 disorientations events have been reported from beaches on Florida's Atlantic coast, the Gulf of Mexico, and the Panhandle (Trindell et al. 2008). A similar finding occurred during the 2007 to 2010 sea turtle nesting season in Florida, where 45,000 to 64,000 sea turtle hatchlings were documented as being disoriented due to artificial lighting (USFWS 2015a).

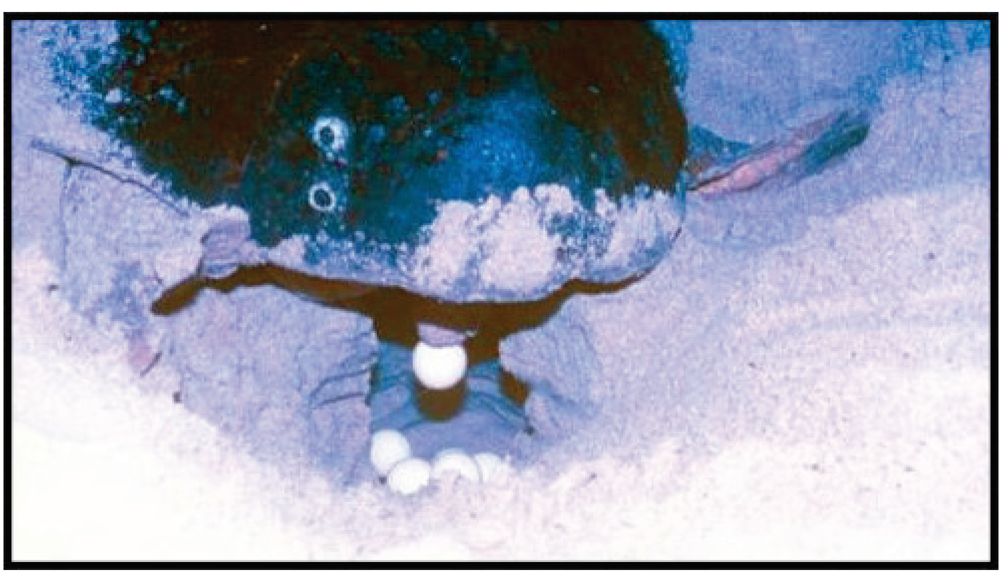
The impact of light can be minimized by reducing the number and wattage of light sources or by modifying the direction of light sources through shielding, redirection, or modification in height. It is important that any light reaching a nesting beach has spectral properties that are minimally disruptive to sea turtles like long wavelength light. Research has established that light sources with longer-wavelengths light (560 nm or more) have less impact on sea turtles (Witherington et al. 2014). The spectral properties of low-pressure sodium vapor lighting are the least disruptive among other commercially available light sources (USACE

2010). In addition to the development of best management practices to reduce lighting during beach nourishment construction projects, efforts have also focused on lighting emanating from beach-front properties, which has the same negative effect of disorientation to emerging hatchlings and nesting females (Witherington et al. 2014, Barshel et al. 2014, USFWS 2015 a,b).

2.5 Nest relocation

Sea turtle nest relocation is a management strategy commonly used to mitigate hatchling mortality, whereby clutches are moved from a threatened site. Figure 2-5 shows a sea turtle laying a clutch of eggs. This nest may be moved to a safer location, an enclosed hatchery, or another section of the beach if deemed to be in an unsafe location. These so called “doomed clutches” (Mrosovsky 2006) can result from tidal inundation (Whitmore and Dutton 1985; McGehee 1990; Foley et al. 2006; Tuttle and Rostal 2010), beach erosion (Boulon 1999; Dellert et al. 2014; Ahles and Milton 2016), and/or beach nourishment activities. Beach nourishment during the nesting season, particularly on or near high density nesting beaches, can result in the loss of sea turtles through disruption of adult nesting activity and by burial or crushing of nests, eggs, or hatchlings, which could significantly impact the long-term survival of the species (USACE 2011).

Figure 2-5. A sea turtle laying eggs in a nest located to close to the high tide water line. The eggs of this nest will be relocated to either a safer location on the beach or to a hatchery. Photo credit: USACE: ERDC.



Nest relocation could cause mortalities to eggs during transfer, negative impacts to hatchlings by altering incubation environments (potentially affecting physiological development), and reduced hatchling success. Limpus et al. (1979) suggested that many nests are simply missed during the relocation effort and that eggs not relocated with 12 hr of deposition are at greatest risk of damage during movement. Martin (1992) and Ernest and Martin (1993) conducted studies on the east coast of Florida where hand digging was performed to confirm the presence of nests and reduce the chance of missing nests through misinterpretation. Trained observers still missed approximately 6 to 8 percent of the nests which were identified as false crawls. A similar result was found in Schroeder (1994), who reported, that on average, 7 percent of all nests are missed by highly experienced sea turtle surveyors, which misidentified the nest as a false crawl.

Missed nests are usually identified by signs of hatchling emergences in areas where no nest was previously documented. Although there are inherent risks in the movement of sea turtle eggs (Hays and Speakman 1992; Witherington et al. 2009), improved site selection and transportation methods have increased hatching success (Tuttle and Rostal 2010). These studies also raise the issue that clutch relocation may concentrate eggs into only a few locations. Hatchlings emerging from concentrated areas may also be subject to greater predation rates from land and marine predators because the predators learn where to concentrate their efforts (Glenn 1998; Wyneken et al. 1998a). Relocation, which is now generally discouraged, of sea turtle nests to less vulnerable sites or into hatcheries was once the most common conservation technique throughout the southeastern US to mitigate the effects of beach nourishment and other human induced factors (Lutcavage et al. 1997). To the maximum extent practicable, all construction activities on the beach will be scheduled to avoid the sea turtle nesting season.

Nest relocation can have adverse impacts on incubation temperature (and hence sex ratios), gas exchange parameters, hydric environment of nests, and hatchling emergence (Limpus et al. 1979; Ackerman 1980; Parmenter 1980; Spotilia et al. 1983; McGehee 1990; Eckert and Eckert 1990; Burney and Mattison 1992; Marcovaldi and Laurent 1996; Rees et al. 2002, Özdemîr and Türkozan 2006; Pintus et al. 2009), or a positive effect when compared to nests facing tidal inundation or predation (Wyneken et al.

1988b; Hockert et al. 1998). Relocating nests into sands deficient in oxygen or moisture can result in mortality, morbidity, and reduced behavioral competence of hatchlings. Water availability is known to influence the incubation environment of the embryos and hatchlings of turtles with flexible-shelled eggs, which has been shown to affect nitrogen excretion (Packard et al. 1984), mobilization of energy reserves of the yolk nutrients (Packard et al. 1985; Packard and Packard 1988), hatchling size (Packard et al. 1981; McGehee 1990), and locomotory ability of hatchlings (Miller et al. 1987).

Moody (1998) studied hatching success of loggerhead turtles on several Florida beaches by comparing relocated nests with ones left in their original locations and found hatching success was lower in relocated nests at nine of the 12 beaches evaluated. In addition, emerging success was lower in relocated nests at 10 of 12 beaches surveyed in 1993 and 1994. Pintus et al. (2009) found no significant differences in hatchling size, incubation temperatures, or sex ratios of green turtle hatchlings between natural and relocated nests; although there was a 20% reduction in hatching success for relocated nests when compared to *in situ* clutches. As reported in the Integrated General Reevaluation Report and Supplemental Environmental Impact Statement (USACE 2009), comparison of hatching success between relocated and *in situ* nests have noted significant variations ranging from a 21% decrease to a 9% increase for relocated nests. Comparison of emergence success between relocated and *in situ* nests has also showed significant variation ranging from a 23% decrease to a 5% increase for relocated nests (USACE 2009). A 1994 study of hatching and emergence success of *in situ* and relocated nests at seven sites in Florida found that hatching success was lower for relocated nests in five of the seven cases with an average decrease for all sites of 5.01 percent (range 7.19 % increase to 16.31% decrease) (Meylan et al. 1995). The authors found that emergence success was lower for relocated nests in all seven cases by an average of 11.7 % (range = 3.6% to 23.4%).

Candan (2017) compared natural and relocated loggerhead clutches on Turkish beaches, including clutches relocated before and after inundation. Candan reported there was a 30% reduction in hatching success for relocated clutches when compared to clutches left *in situ*. Egg failure rates were similar for both clutches (relocated vs *in situ*) for early-stage embryos but increased 2 to 3-fold by mid- and late-stage development. Ware and

Fuentes (2018) assessed the differences in temperature, grain size, and moisture content between the original and final locations of relocated nests at a loggerhead nesting beach in Fort Morgan, Alabama. Like many other studies, there were no significant differences in the parameters between *in situ* and relocated nests; however, emergence success was significantly lower for relocated nests. Relocation of sea turtle nests is generally performed within 12 hr of deposition to avoid damaging fragile respiratory membranes as they attach to the egg (Ahles and Milton 2015). They found that mean hatch success was only 53% for nests moved mid-incubation, versus 79-90% for nests moved within 12 hr of deposition.

In some studies, relocated nests demonstrated greater hatchling success than their *in situ* counterparts (Wyneken et al. 1988a; Hoekert et al. 1998; Baskale and Kaska 2005; Tuttle and Rostal 2010). Apart from Wyneken et al. (1988a), all relocated nests were to alternative beach sites, including both natural and renourished beaches. Wyneken et al. (1988a) relocated some nests to polystyrene incubators and other beach sites. The authors cited above reported that eggs in undisturbed natural nests had lower hatching success than relocated eggs when compared to polystyrene incubators. Eggs placed at alternate beach sites also had a higher hatching success rate than nests at undisturbed sites. It was concluded that egg relocation is an effective conservation method, provided sites are chosen carefully. Ilgaz and Baran (2011) demonstrated the hatching success of transplanted nests to be higher (72.8%) than under natural conditions (55%) for loggerhead turtles in Northern Cyprus and Turkey. Likewise, Baskale and Kaska (2005) reported that relocation clearly increased the hatching success rate of loggerhead turtles and provided effective protection of nests against inundation and predation. Positive effects on hatching success of leatherback turtles were also reported by Dutton et al. (2005).

Ilgaz et al. (2011) studied the relationship between nest factors (nest moisture, depth, diameter etc.) and embryonic mortality of natural and relocated nests at Dalyan Beach, Turkey. Ilgaz et al. (2011) reported that clutches in natural and relocated nests have a total mortality ratio of 21% and 12%, incubation duration of 52 and 50 days, and an estimated female ratio of 80% and 88%, respectively. Overall, mortality was lower and incubation times faster in the relocated nests, but the proportion of females was higher. Hatching success in relocated nests (84.4%) was significantly higher than in natural nests (72.7%) (Ilgaz et al. 2011).

Dellert et al. (2014) reported the effects of beach nourishment and nest relocation on the success of loggerhead turtle eggs and hatchlings. Over a 6-yr period in Pinellas County, FL, data were collected on 53,700 eggs from 517 clutches in danger of inundation. The proportion of eggs hatched and hatchlings that emerged on relocation from natural and nourished beaches were compared. Beach nourishment was found to have no adverse effect on the proportion of eggs that hatched or the proportion of hatchlings that emerged.

Given that water inundation can destroy most of the eggs in a clutch, nest relocation may be considered a best management practice for sea turtles when no other alternative is available. As much as 38% of the world's beaches may experience a loss in nesting habitat due to inundation (Fish et al. 2005; Fuentes et al. 2010). As sea level rises, turtles may not be able to nest far enough from the mean high-water line. Inundation of nests causes the hatchling success of the nest to decrease, with nests completely inundated having the lowest hatchling success (Foley et al. 2006; Pike and Stiner 2007). Shaw (2013) found that hatch success for loggerheads decreased by 2.9% after one day of inundation, 27.2% after two days, and 77% after three days of inundation relative to the hatching success of nests that were never inundated (86.6%). Pike et al. (2015) studied inundation on the hatch success of green sea turtle eggs collected from Raine Island, Australia, the largest green turtle nesting rookery in the world and found that inundation for 1 to 3 hr reduced egg viability by less than 10%, whereas inundation for 6 hr reduced viability by approximately 30%. To date, numerous studies have investigated the effects of tidal wash-over and inundation on nest temperature (Schmid et al. 2008), developmental stage of the embryonic arrest (Foley et al. 2006; Caut et al. 2010), emergence success (Coll 2010), and hatch success (Mrosovsky et al. 1983; Whitmore and Dutton 1985, Pike and Stiner 2007, Coll 2010) of multiple turtle species with varying results. Research suggests that not only the occurrence of a wash-over event has the potential to decrease hatching success, but also the timing, frequency, and level of the wash-over/inundation event (Foley et al. 2006; Caut et al. 2010; Coll 2010; Brig 2014; Shaw 2015).

An additional concern to resource management agencies is that the relocation of eggs may alter or distort gene pools, particularity if nest site selection is a heritable trait. If individuals exhibit consistency in their nest-site selection, then relocating eggs deposited in vulnerable locations may impose artificial selection and may be unfavorable for long-term conservation of the population (Mrosovsky 1983, 2006, 2008). However, if most turtles scatter their nests, then distorting the gene pool may be less of a concern (Mrosovsky 1983; Pike 2008a). In the absence of disturbance, loggerheads tend to lay nests in non-random patterns (Hays and Speakman 1993; Mellanby et al. 1998). Pfaller et al. (2008) measured the perpendicular distance of the nests to the dune baseline and predicated the fate of loggerhead clutches in terms of tidal inundation on nesting beaches in Queensland, Australia. Selection of unsuccessful nest sites was distributed across the population indicating turtles scatter their nests, and nest-site selection may not be a heritable trait. Eighty percent (80.3%) of the turtles monitored selected at least one unsuccessful nest site during their initial nesting attempt. This occurred more frequently with younger nesting females. It was concluded that relocating eggs vulnerable to tidal inundation does not substantially distort the gene pool in the eastern Australian loggerhead stock and that relocation, whether on a natural or nourished beach, remains a viable strategy for the conservation of marine turtle populations.

The USFWS discourages widespread use of this technique given the perceived negative impacts; however, in some instances where beach nourishment activities occur during the nesting season, nest relocation is used as a management tool to relocate nests laid in the impact area to areas not susceptible to disturbance. Beach construction projects must be scheduled, to the extent possible, outside of the sea turtle nesting season in order to avoid impacts to nesting females and the nest incubation environment. Guidance from the USFWS states that only those nests that may be affected by sand placement activities will be relocated. Nest relocation shall not occur upon completion of the project. The USFWS requires relocation occur no later than 9 a.m. the morning following deposition to a nearby self-release beach site in a secure setting where artificial lighting will not interfere with hatchling orientation (USFWS 2015). Relocated nests shall be randomly staggered along the length and width of the beach in locations not expected to experience daily inundation by high tides or known to routinely experience severe erosion and egg loss, predation, or be subject to artificial lighting.

2.6 Nesting beach habitat factors

All species of marine turtles share a similar sequence of nesting behaviors, which are described in detail by Miller et al. (2003). In brief, successful nesting requires the female to locate her natal beach, ascend the beach profile, excavate an egg chamber, deposit her eggs, and ensure the nest is sufficiently buried and camouflaged. However, nest site selection is not completely understood, and many studies have been contradictory (Miller et al. 2003). Since adult sea turtles provide no parental care, reproductive success is highly dependent on selecting an appropriate nest site with suitable incubation conditions (Rafferty and Reina 2014). Assessing the effects of beach nourishment on the nesting process and hatchling survival is difficult since the physical characteristics of an optimal beach habitat are unknown.

Loggerhead and green turtles exhibit a pattern that includes pressing their heads into the sand as they ascend the beach, perhaps to monitor microhabitat characteristics of potential nest sites (Wood and Bjorndal 2000). Additionally, characteristics making one beach an acceptable sea turtle habitat, may not be critical factors at others (Salmon et al. 1995 a, b; Hendrickson 1995). Generally, to be an acceptable habitat, it must meet several minimum requirements listed below (Mortimer 1990).

1. Easy accessibility to and from the ocean.
2. High enough elevation to avoid being inundated by high tides.
3. Adequate moisture content allowing for nest construction and successful hatching.
4. Compatible sediment content to facilitate gas diffusion and maintain optimal temperatures conducive to egg development.

Over the past several decades, studies have suggested that reduced sea turtle nesting success on nourished beaches may be due to several factors including beach armoring, altered sediment type, altered grain size, increased beach shear resistance (beach hardness), altered beach profile, escarpment formation, and unfavorable nest microclimate factors.

2.6.1 Beach protection with hard structures

On highly developed shorelines with significant beach erosion problems, hard structure alternatives may be used for beach stabilization, in combination with sand placement activities, to control the loss of sediment over time. These include seawalls (Figure 2-6), revetments, groins, bulkheads, and breakwaters. Seawalls, revetments, and bulkheads are built parallel to the shore to protect the area immediately behind them but afford no protection to adjacent areas or beach sediments in front of them. Because hard structures can affect adjacent beaches by modifying coastal sediment transport processes (e.g., longshore and cross-shore transport rates) and disrupt normal functioning of the beach environment, careful consideration must be given before they are used (Rizkalla and Savage 2011).

Hard stabilization measures effectively protect property but tend to result in beach narrowing or loss which can exacerbate erosion (Beatley et al., 2002; Bouchard et al. 1998). Pilkey et al. (1984) are critical of seawalls as they increase the intensity of longshore currents and prevent the exchange of sand between dune and beach zones. Hence, the beach cannot flatten during storms and dissipate wave energy, leading to increased erosion. Degradation of the beach due to passive erosion can take many years and will depend on the type of structure and is highly variable between beaches (Plant and Griggs 1992). These structures can affect sea turtles by preventing access to suitable nesting sites, impeding and/or trapping nesting females, abandoning nesting attempts, preventing proper nest construction, increasing clutch mortality due to frequent inundation or erosion, and overall loss of nesting habitat due to long term beach erosion (Schroeder and Mosier 1998; Lucas et al. 2004; Mosier and Witherington 2002; Witherington et al. 2005; Dugan et al. 2008).

In Florida, where most sea turtle nesting takes place in the United States, approximately one-quarter of beaches along the east coast are associated with some type of hard structure placed parallel to the shoreline, with bulkheads and seawalls being the most common (Schroeder and Mosier 1998) (Figure 2-6). The book "*Living with Florida's Atlantic Beaches*" states that 45% of Florida's developed east coast and 50% of Florida's developed west coast are associated with hard structures (Bush et al. 2004).

Figure 2-6. An example of a hard structure (e.g., seawall) used to protect property from erosion. Photo Credit: USACE: Jacksonville District.

In Mosier's (1998) study of the impact of coastal armoring structures on sea turtle nesting behavior, seawalls were shown to have detrimental effects on sea turtle nesting. Mosier reported that fewer turtles emerged to nest in front of seawalls when compared with adjacent unaltered beaches, suggesting that nest site selection was made before the turtles emerged onto the beach. Of three nesting beaches on the east coast of Florida, Mosier reported that 86% of nesting females encountering a hard structure during emergence returned to the water without nesting because of the inability to access higher elevation nesting habitat. Lucas et al. (2004) designed a study to assess sea turtle response to hard structures and found they emerged onto portions of the beach where anthropogenic structures were present; however, upon encountering the structure, they abandoned the nesting sequence.

Mosier and Witherington (2002) and Witherington et al. (2001) studied nesting behavior and nest-site selection of loggerhead sea turtles encountering a temporary seawall, (2-m wide x 1-m high) constructed of PVC and held in place by a PVC tubular framework. The position of the portable wall was parallel to the shore and midway between the wrack line and the toe of the dune. No significant difference was found in nesting success for turtles encountering the wall or those nesting at a control site with no wall. The only effect from the wall was that turtle nests were 3.5 m closer to the surf at the control site. Although the wall affected the location where nesting occurred, there was no observable effect on the effort turtles made to prepare the nest site, dig an egg chamber, fill and cover eggs, or camouflage the nest site (Witherington et al. 2011).

Rizkalla and Savage (2011) studied the impact of seawalls on loggerhead sea turtles nesting and hatching success over a 7-yr period. Nesting patterns indicated that passive erosion at seawalls likely caused fewer turtles to attempt to nest when compared to nesting on an unaltered beach. Nests placed in front of seawalls were more likely to be washed away in storms. Finally, Herren et al. (2007) also found no impact of seawalls on hatching success, but suspected results would differ if the study was conducted during a more active storm season.

Groins (i.e., T-head), both straight and composite designs and jetties (Figure 2-7), may also impact sea turtle nesting. Foote and Mueller (2002) and Davis et al. (2002) found these structures acted as an impediment and/or a trap to nesting females and/or hatchlings. To prevent trapping of hatchlings, fencing is typically used to redirect hatchlings away from the groin during hatch out. Studies indicated that 12% of the hatchlings were redirected from potential entrapment. These structures may negatively impact sea turtle hatchings by causing increased energy expenditure to transverse around the structure, depleting the critical reserves necessary to reach the safety of offshore nursery areas. In addition, bird and fish predators tend to congregate around high relief structures, potentially adding to mortality rates. Jetties placed at ocean inlets to keep sand from closing the inlet channel may also negatively impact sea turtle nesting. Witherington et al. (2005) found a significant negative relationship between loggerhead nesting density and distance from the nearest of 17 ocean inlets on the Atlantic Coasts of Florida. The effect of inlets in lowering nesting density was observed both up- and down-drift of the inlets. It was proposed that beach instability from erosion and accretion may discourage loggerhead nesting.

Figure 2-7. A series of T-Shaped groins, man-made structures designed to trap sand as it is moved down the beach by longshore drift. Photo Credit: USACE: Jacksonville District.

2.6.2 Compaction and shear resistance

Sediment placed on the beach during beach nourishment projects is typically derived from inlets, channels, or offshore borrow sites (Crain et al. 1995). Significant alterations to the natural beach substrate can result when sediment does not match the pre-existing sediment characteristics with respect to density (compaction), shear resistance (hardness), beach slope, color, grain size, grain shape, and mineral content. Nourished beaches frequently appear to be harder than natural beaches, which is a byproduct of the nourishment process, specifically the way sand is transported to the shore. Sand is transported in a water slurry inside a long pipeline that extends from the dredge to the active project area. This process mixes the different sized sand grains and creates a nourished beach with a fairly homogenous sand grain distribution; the end results of which is a compacted beach (Nelson and Mauck 1986; Magron 2000; Mota 2009). Compaction affects water retention, permeability, exchange of gases and nutrients, and may decrease turtle nesting success by impeding nest excavation and preventing hatchling emergence (Raymond 1984; Ryder 1993; Milton et al. 1997; Herren 1999; Steinitz et al. 1998; Defeo et al. 2009). Kikukawa et al. (1998, 1999) found that of 23 characteristics studied (e.g., temperature, moisture, sand color, etc.), the most important parameter in nest site selection was sand compaction.

While much of the literature refers to compaction (density) as the reason for the reduction in turtle nesting on nourished beaches, Ackerman (1997) concluded the issue is related to shear resistance (i.e., beach hardness; commonly expressed in relative values of pounds per square inch [psi or kg/cm^2]). Increased shear resistance can be due to increased sand compaction but can also be due to the sand particle characteristics (size, shape) and the interactions between these particles (Nelson and Dickerson 1987, 1988, 1989; Nelson et al. 1987; Ackerman 1997). Thus, a measurement of increased shear resistance does not indicate if the beach is more compact or dense. Beach fill with a clay or silt content higher than 5-10 percent may cause high shear resistance once the sediment dries (Nelson and Dickerson 1987).

Harder or more compact nourished beaches with high shear resistance values typically result from angular, finer grain sand dredged from low energy offshore borrow sites, whereas lower shear resistance values result from smoother, coarse sand dredged from high energy locations (e.g., inlets). Natural beach formation results in extensive sand sorting by layers and within layers. In contrast, beach creation with heavy equipment can impart a component of "compactness" that should not occur on natural beaches (National Research Council 1995). The USFWS (2010) requires monitoring for compaction for three seasons following beach nourishment unless it is tilled prior to the nesting season each year (USFWS 2015b). Compaction values exceeding 500 psi are critical thresholds based on guidelines established by the USFWS, which were based on results of studies conducted by Nelson et al. (1987) and Nelson and Dickerson (1988). The use of "beach compatible" sand was not a requirement during beach renourishment projects conducted in the early 1980s. As a result, coarse sand with high shell content was often used. Given that "beach compatible" sand is a best management practice and requirement for sea turtle friendly beaches, compaction values established by the studies may not be representative of beach conditions from modern beach nourishment projects,* and that tilling may no longer be a necessity.

* Personal Communication. Dena Dickerson, ERDC sea turtle expert, November 7, 2019.

Significant reductions in nesting success (i.e., number of false crawls) have been documented on severely compacted nourished beaches (Mann 1977; Raymond 1984, Nelson and Dickerson 1987). Fletemeyer (1984) also reported an increase in the number of shallow nests following a beach nourishment project in southeastern Florida. Egg clutches closer to the sand surface are more prone to desiccation as well as more susceptible to predation (Rumbold et al. 2001). However, Raymond (1984) concluded that if shear resistance (compaction) of the nourished substrate prevented females from digging in the sand and was a major factor in the decrease in nesting success, a large portion of abandoned egg chambers or shallow nests with overflowing eggs would be expected. Raymond also observed very few abandoned nest chambers (166 out of 4,206 non-nesting emergences) and no nests with overflowing eggs in nourished beaches. It is likely that female turtles may respond to harder physical properties of the beach by spending more time on the beach nesting, which may result in physiological stress and increased exposure to disturbances and predation; thus, in some cases leading to a false dig (Nelson and Dickerson 1989).

Even though high shear resistance does not occur with every nourishment project, higher values are more frequently recorded from nourished beaches than on natural beaches within the same area. The natural variance in shear resistance values, as well as sea turtle nesting and hatching success related to these values, is still poorly understood (Trindell et al. 1998). Davis et al. (1999) studied compaction on three adjacent nourished beaches and a nearby unnourished beach for two years. Compaction values obtained by cone penetrometer measurements in this study routinely exceeded guidelines (500 psi) for turtles. The beaches typically had large quantities of bivalve shell fragments making vertical penetration difficult leading to high compaction values; however, turtles found little resistance in digging nests even when compaction values greatly exceeded the current guidelines. It was suggested that the current guidelines based on cone penetrometer data for nesting on highly compacted beaches are incorrect.

2.6.3 Beach fill material

According to USACE (2011), beach compatible fill must maintain the general characteristics and functionality of the material naturally occurring on the beach and in the adjacent dune system. Such material must be composed predominately of carbonate, quartz, or similar material with a particle size distribution ranging between 0.062 and 4.76 mm and classified as sand by the Unified Soil Classification System (ASTM 2006). The placed sediment must be similar in color and grain size distribution (sand grain frequency, mean and median grain size, and sorting coefficient) to the material in the historic beach sediment at the site, and must not be:

1. greater than 5%, by weight, silt, or clay passing the #230 sieve,
2. greater than 5%, by weight, fine gravel retained on the #4 sieve,
3. coarse gravel or cobble material retained on the ¾ inch sieve in a percentage or size greater than found on the native beach,
4. must not contain construction debris, toxic material, or other foreign matter, or
5. material that will result in cementation of the beach (USACE 2011).

A review of the analysis procedures to determine grain size distribution of a native beach scheduled to be renourished can be found in Gravens et al. (2008).

Sediment grain size is the most important borrow material characteristic (Gravens et al. 2008). It will affect the shape of the nourished beach, the rate at which fill material is eroded from the project, and the biological habitat (Dallas et al. 2012). Coarse sediments will provide greater resistance to erosion but may reduce recreational value to the user of the beach or impact biological habitat, such as sea turtle nesting ability. Cisneros et al. (2017) studied the effects of placed sand from a nourishment project in Palm Beach County, FL to assess sea turtle nesting and hatching patterns. Sediment was obtained from inlets, offshore, and upland mined sand for both beach and dune construction. Each source differed in their sorting characteristics and the amount of carbonate content present. Lower nesting and hatching success occurred within the project areas that used a relatively larger grain size or higher carbonate content in comparison to the native beach material.

2.6.4 Beach profile (width/slope/elevation)

The three phases of nest site selection in sea turtles are beach selection, emergence of the female, and nest placement. The altered profile of a nourished beach may interfere in beach selection, but the mechanisms sea turtles use in nest site selection are not well understood (Dodd 1988). One proximal cue that may be used to indicate where sea turtles place nests is beach slope and width (Provancha and Ehrhart 1987; Horrocks and Scott 1991; Wood 1998; Wood and Bjorndal 2000; Mazaris et al. 2006), given that it is the one environmental factor, unlike temperature or sediment moisture, with the least variability over time (Wood 1998; Byrd 2004).

Mazaris et al. (2006) found that an inclination of 15% in beach slope was a secondary factor used by turtles to choose a nest site, after beach width. While beach nourishment has the potential to help sea turtle populations by increasing nesting habitat otherwise unavailable, it can also change parameters of the natural beach that may affect nesting and reproductive success (Byrd 2004). Alternatively, severely eroded beaches with little or no dry foredune habitat can result in increased nesting activity, particularity when the placed sand is highly compatible (i.e., grain size, shape, or color) with naturally occurring beach sediments in the area (Ernest and Martin 1999).

Proponents of beach nourishment support the belief that a wide beach creates a larger, more effective barrier to storm surge and wave action which reduces flooding, erosion, and damage to upland structures (National Research Council 1995). Beach width correlates well with the amount of beach space available for sea turtle nesting; however, wider beaches are more attractive to human activity, which, in turn, can disturb nesting sea turtles and their hatchlings (Kikukawa et al. 1999). Although, it is generally accepted that the elevation of the design berm should correspond to the natural berm crest elevation (Dean 2002; Gravens et al. 2008), beach nourishment projects tend to create an elevated, wider, and unnatural flat slope berm. The lag between the completed construction and the corrected berm profile, what the constructed berm is supposed to equilibrate to, may negatively influence loggerhead sea turtle nesting (Brock et al. 2007). However, construction of a higher berm may also produce a steeper beach face slope than the natural berm and prevent turtles from crawling up the beach to nest (Steinitz et al. 1998).

Design berm (beach) width depends on several factors including project economics and environmental resources. For Federal beach nourishment projects, berm width is calculated through a process of optimization (costs and benefits) based on storm damage reduction (Gravens et al. 2008).* Current guidance from the USFWS states that the beach profile template for the sand placement project shall be designed to mimic the native beach berm elevation and beach slopes landward and seaward of the equilibrated berm crest (USACE 2015a).

Loggerheads and green turtles typically prefer a narrow, steeply sloped beach with gradually sloped offshore approaches that have moderate to high-energy where turtles tend to cluster their nests near the base of the dune above the high-water line (Provancha and Ehrhart 1987, Hays et al. 1995). However, Garmestani et al. (2000) assessed several beach characteristics on nesting densities (e.g., beach width and slope, beach length and height of canopy) in Florida’s Ten Thousand Islands and found loggerheads were not deterred from using wide beaches (> 8.5 m) that were more gently sloped. It was also found that loggerheads preferred beaches with fewer shells (low amounts of calcium carbonate in the nesting substrate). Loggerheads and green turtles also tended to favor and were generally found near the supra-littoral vegetation zones of beaches (Whitmore and Dutton 1985; Foley et al. 2000, 2006; Garmestani et al. 2000; Turkozan et al. 2011).

In Veracruz, Mexico, Zavaleta-Lizárranga and Morales-Mávil (2013) reported greater nesting densities for green turtles on beaches with fine sands, moderate slopes, good humidity, and drainage with dunes, particularity those with vegetation, whose distance averaged 22.6 m from the tidal line. For loggerheads, the average nesting distance from the tidal zone was 21 m (Wood and Bjorndal 2000), while hawksbill turtles favored beaches with steep slopes and low wave energy (Horrocks and Scott 1991). Selecting a more gently sloping beach may protect the nesting female and hatchlings with a quicker retreat to the water while the steeper beach slopes may provide some increased nest protection from inundation or washouts. On the wider, gently sloped nourished beach, loggerheads deposit eggs closer to the water where the nests are more vulnerable to washout during beach equilibration. Nests placed along the dune of a wider beach may produce hatchlings that are more vulnerable to physiological stress, desiccation, and predation due to the increased distance to the sea. In a study by Wetterer et al. (2007), it was found that

* A review of beach fill design can be found in the Coastal Engineering Manual, Part V, Coastal Project Planning and Design (Gravens et al. 2008).

turtle nests placed closer to dune vegetation had significantly greater exposure to invasive red fire ants (*Solenopsis invicta*) (see Moulis 1997, Allen et al. 2001) leading to higher predation rates. Moulis and Allen et al., noted that differences in ant presence on turtle nests between years and among turtle species were closely related to differences in nest placement relative to dune vegetation. Beach nourishment significantly lowered exposure of the nests to ants because they nest farther from the dune vegetation on wider beaches. Typically, within two years, nesting success returns to historical pre-nourishment values of the natural beach once nourished beaches are reworked by wave action, for example (Gallaher 2009).

Beach elevation is thought to be a primary factor in nest site selection. Some researchers note that elevation serves as a trade-off, whereby the cost of exposure to predation and energy extended in search of a site balanced by the reproductive benefit of finding an incubation site with maximum hatchling emergence success (Horrocks and Scott 1991; Wood and Bjorndal 2000). In general, all sea turtle species tend to nest above the high-water mark to reduce the risk of tidal inundation or egg wash out (Mortimer 1982). Some studies show that changes to the natural beach profile (width and slope) may be primarily responsible for the post-nourishment decline in sea turtle nesting success, as turtles tended to nest closer to the water line after nourishment (Ernest and Martin 1999) rather than an increase in beach shear resistance and escarpment formation as suggested in other studies (Wood and Bjorndal 2000, Brock et al. 2005).

Wood and Bjorndal (2000) examined the relationship between slope, temperature, moisture, and salinity to nest site selection in loggerhead turtles. They reported a strong correlation between slope and nest site selection, presumably related to nest elevation. There was no correlation found among the other parameters. Nesting success of loggerhead and green turtles were evaluated by Brock et al. (2007) where nourished and non-nourished beaches were compared. A reduction in nesting success for both species on the nourished beaches was found. The negative effect lasted for one season in loggerheads and for at least one season in green turtles. It was concluded that the fill sand did not impede nesting attempts, but also that the altered beach profile was not favorable for nest deposition. Reproductive output was 52.2% lower for loggerheads, 1-yr post-nourishment. By the second year of post-nourishment, there was a

44.1% increase. For green turtles, there was a 0.8% reduction in the first season post-nourishment, despite a 13% increase in the non-nourished areas.

Trindell et al. (1998) reported that a significantly larger proportion of turtles emerging on nourished beaches abandoned their nesting attempts than turtles emerging on a natural beach, even though more nesting habitat was available (Ernest and Martin 1999). Trindell reported a reduction (10 to 34% lower) in nesting success when comparing nourished beaches to unnourished control areas. The reduction in nesting success was more pronounced during the first nesting season after nourishment, likely attributed to changes in the physical beach characteristics (i.e., beach profile, sediment grain size, and beach compaction). One observation from Trindell et al. (1998) was that during the first year of post-construction, the time required for turtles to excavate an egg chamber increased significantly. Excavation times were not significantly different on beaches tilled to a depth of 36 in., which is the depth required by USFWS (1015a).

Rumbold et al. (2001) compared a nourished beach (Jupiter) with two natural beaches (Juno and Tequesta) in Palm Beach County, FL. After nourishment, loggerhead turtle nesting declined by 4.4 to 5.4 nests per km per day while false crawls increased from 5.0 to 5.6 per km per day on the nourished beach when compared to the natural beach during the first season. Although the effect was less pronounced, nesting was still lower during the second season after nourishment by as much as 1.6 nest per km per day when compared to the control beach. False crawls (0.7 to 0.9 FC per km per day) were also reduced but still greater than the natural beach. Ozan (2011) studied the hatching and emergence success of nourished and natural beaches in Pinellas County, FL over five nesting seasons (2006-2010). Nesting and false crawl densities were found to differ significantly between natural and nourished beaches during three of the five nesting seasons. However, no significant differences were found between hatching and emergence success rates between natural and nourished beaches over the course of the study. However, an analysis by nesting season did show that average hatching and emergence success rates were always significantly lower on the nourished beach compared to the natural beach.

Byrd (2004) found no significant difference in nesting and false crawls among natural and nourished beaches in South Carolina. Significant differences among the beaches in terms of sand temperature, compaction, grain size, and moisture content were noted. The nourished sand was warmer, more compact, had a coarser and wide grain size distribution, and had less moisture than the reference beach. Byrd reported the differences were typically small and may not have been biologically meaningful. A more recent study by Maurer and Johnson (2017) concluded that loggerhead crawl lengths decreased as beach slope increased. A comparison of nest crawls resulting in egg laying versus false crawls (no egg laying) suggested to that beach slope and crawl length differ between crawl types, but elevation does not. In short, loggerheads may cue to the beach slope to reach a predetermined elevation, crawling longer distances on flatter slopes and shorter distances on steep slopes, but after the achieved elevation is reached, other environmental variables determine if a nest is dug, and eggs are laid. Sea turtle eggs need adequate humidity, salinity, respiratory gases, and temperature for normal development, which can only be supplied by their local environment (Ackerman 1997).

Ernest and Martin (1999) noted that it is unknown whether nests that would have been laid in a nourished area during the year of post-nourishment are lost from the population or if nesting is simply displaced to adjacent beaches. Meylan and Donnelly (1995) pointed out that the argument that turtles prevented from nesting on their preferred beach simply go elsewhere is shortsighted because it ignores the concept of nest site fidelity. Pritchard (2004) suggests the degree of site fidelity may be flexible when nesting conditions are not satisfactory. He noted that there was a large shift in spatial nesting distribution for three species of sea turtles in South America following geomorphologic changes to the nesting beaches. Although site fidelity is well documented in marine turtles, dating back to the 1960s (Hughes et al. 1967), LeBuff (1974) reported a tagged loggerhead that nested on the lower Gulf coast was discovered nesting on the Atlantic coast of Florida over four years later. This was the first recorded incident where an individual turtle had made egg laying emergences on both coasts of Florida at considerable distances from each other.

2.6.5 Escarpments

On nourished beaches, steep escarpments (Figure 2-8) may develop along the water line interface as the beach adjusts from an unnatural construction profile to a more natural beach profile (Coastal Engineering Research Center 1984; Nelson and Dickerson 1987). Escarpments are defined as a continuous line of cliffs or steep slopes facing in one general direction, which is caused by erosion or faulting (Figure 2-8). Depending on the shoreline response to the wave climate and subsequent equilibrium process, the slope, both above and below mean high water may vary outside of the natural beach profile; thus, resulting in escarpment formation. Although escarpment formation is a natural response to shoreline erosion, the escarpment formation because of the equilibration process during a short period following beach nourishment event may have a steeper and higher vertical face than a natural escarpment formation. This response is likely due to increased beach shear resistance and a change in beach profile (Ackerman 1997; Dean 2002).

Figure 2-8. An example of an escarpment formed after beach renourishment. Photo credit: USACE: Jacksonville District.

Large escarpments often form on recently nourished beaches (Figure 2-8), which can impede turtles from reaching nesting areas and increasing the number of false crawls (Raymond 1984; Ryder 1993; Crain et al. 1995; NRC 1995; Lutcavage et al. 1997; Nelson and Blihovde 1998; Trindell et al. 1998; Steinitz et al. 1998; Ernest and Martin 1999; Herren 1999; Rumbold et al. 2001). Nests established below the escarpment have a greater potential to be lost due to flood tide inundation (Steinitz et al. 1998; Herren 1999).

Parameters considered by adult female turtles surveying the nesting beach from the water include the geomorphology and dimensions of the beach (Mortimer 1982; Johannes and Ramer 1984) and bathymetric features of the offshore approach (Mortimer 1982). Reports of increased nesting on natural beaches may be the result of escarpments creating barriers to the successful nesting on nourished beaches. Ernest and Martin (1999) documented increased abundance of nests located further from the toe of the dune on nourished versus controlled beaches. These nests are created potentially in a high-risk area where vulnerability to sloughing and equilibration are greatest. Some studies have also reported no significant difference between scarp height and nesting success rate between nourished and natural beaches (Ernest et al. 1995; Brock 2005). However, any nest located below or close to escarpments are vulnerable to inundation and erosion. As a nourished beach is reworked by natural processes and the construction profile approaches a more natural profile, the frequency of escarpment formation declines and the risk of nest loss due to sloughing of escarpments is reduced. According to Brock (2005), the return of loggerhead nesting success to equivalent rates like those on the adjacent non-nourished beach and historical rates required two seasons post-nourishment, before return of success rates was observed. The return of nesting success rates is attributed to the equilibration process of the seaward crest of the berm.

To avoid negative impacts on sea turtle nesting, visual surveys for escarpment formation must be conducted along the project area and be completed immediately after the completion of the beach nourishment project. This requirement must be completed 30 days prior to March 1st. Escarpments interfering with sea turtle nesting or that exceed 18 in. in height for 100 ft must be leveled, and the beach profile must be reconfigured to minimize scarp formation. Surveys for escarpments must be conducted weekly during the three nesting seasons following completion of the project (USFWS 2015a). The USFWS must be notified to the number, location, and height of the escarpment as well as the maximum height of each escarpment.

2.6.6 Nest chamber geometry

The shape and dimensions (i.e., depth, diameter) of the nesting chamber are critical to the success of the newly laid clutch of eggs (Ackerman 1980). Beach shear resistance may influence the nest chamber geometry due to the female's limited ability to dig in the beach fill and the chamber's ability to maintain its shape once dug. Along the nourished beaches of east Florida, studies have reported the nest chamber geometry of shallower sea turtles' nest were adversely altered from the characteristic flask shape nest (Fletemeyer 1984; Ryder 1993). By adversely altering the geometry of the nesting chamber, eggs could spill out of the nest, developing embryos may not be adequately concealed, or the microclimate of the nest chamber could be significantly degraded. Carthy (1994) studied loggerhead nest geometry in native and nourished sand in Melbourne Beach, FL. Increased sand compaction was related to differences in nest dimensions, particularity to nest neck length, nest cavity depth, and minimum egg depth. These parameters were related to turtle size (carapace length and width) and rear flipper length. These factors influenced the turtle's ability to pivot its plastron vertically in hard sand to add length to digging strokes. Melbourne Beach, with native soft sands, did not show significant differences between the variances of these three nest dimensions (Carthy 1994). More research is needed to fully understand the impacts of beach nourishment on nest chamber geometry.

2.6.7 Nest concealment

Increased shear resistance may make it more difficult for female turtles to scrape and gather enough loose sand to adequately conceal a newly laid clutch of eggs from potential predators. Nelson and Dickerson (1987, 1989) found no difference between nourished and natural beaches along Delray Beach, FL (Palm Beach County) in the time females spent during the camouflaging phase of the nesting process, but Ryder (1993) found many females failed to adequately cover the nest on nourished sections near Sebastian Inlet State Recreation Area, FL (Brevard County). Nests not properly concealed on nourished beaches had a 9% higher predation rate from raccoons compared to natural beaches. Other potential factors (e.g., a higher predator population) make nest concealment difficult to evaluate.

2.6.8 Beach tilling

Depending on the compatibility of sediment placed on the beach and the post-compaction levels, tilling the nourished beach may be required (Figure 2-9). Compaction sampling stations should be located at 500-ft intervals along the sand placement template (USACE 2010). Compaction levels are determined by cone penetrometer readings taken to a depth of 6, 12, and 18 in. in replicates of three. These three replicate compaction values for each depth must be averaged to produce a final value for each depth at each station. If the average value for any depth exceeds 500 lbs per square inch (psi) for any two or more adjacent stations, the area must be tilled to a depth of 24 to 36 in. Tilling entails pulling a series of tines through the sediment using a tractor or suitable piece of heavy equipment (Figure 2-9). This is performed after the design beach profile is achieved. Tilling is often performed in a series of overlapping parallel and perpendicular rows until no furrows are left behind. All tilling activities must be completed by May 1st, after which, tilling can only be performed after coordination with the appropriate sea turtle beach monitoring representatives. Tilling after May 1st is not allowed in areas where nests have been left in place or relocated. After the beach is tilled, it is smoothed by dragging a piece of fencing or similar type object across the surface. Sand compaction must be monitored in the nourishment area immediately after project completion and prior to March 1st for three subsequent years following the protocol agreed to by the USFWS (USACE 2015a, 2010).

Figure 2-9. Tilling a newly renourished beach in Martin County, FL. Photo credit: USACE: Jacksonville District.

This practice was originally recommended over 30 years ago as a mechanical method to loosen hard beach sediments after nourishment projects to within comparable levels of neighboring unnourished beaches (Nelson 1985; Nelson and Dickerson 1987, 1988). Although beach tilling is now a common practice (USFWS uses a criterion of 500 psi [35.2 kg/cm^2]) (USACE 2015a) for nourished projects throughout the southeastern US, there is much debate regarding the effectiveness of tilling to reduce shear resistance and the potential effects it has on sea turtle nesting or hatching success.* Results vary widely regarding the effectiveness of tilling for sea turtle nesting (e.g., Ernest et al. 1995; Trindell et al. 1998; Davis et al. 1999, Davis et al. 2002; Brock 2007, 2005). These include conclusions of increased and decreased, as well as no change, in nesting and hatching success rates. While tilling does produce a more friable beach sediment after nourishment projects, it is unknown if this technique really improves the suitability of the beach for sea turtle nesting. Tilling may not duplicate the native beach conditions and the shear resistance values may increase again after several months.

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* Personal Communication. Dena Dickerson, ERDC sea turtle expert, November 7, 2019.

2.6.9 Nest microclimate requirements

The semipermeable nature of reptile eggs makes them extremely vulnerable to changes in the nest microclimate (Packard and Packard 1988). The nest microclimate is created by an interaction between the physical characteristics of the beach sediment, the physical structure of the beach, local climate, and eggs in the clutch. Nourishment projects may affect the nest microclimate, thereby affecting hatchling development and survival. Sediment grain size, and the mechanical placement of the material on the beach may affect the hydric, thermal, respiratory, and osmotic properties of the environment surrounding the buried eggs (Ackerman 1975, 1980 a, b, 1991, 1994, 1997). Water potential of a beach can impact respiratory and osmotic properties of a clutch throughout incubation (Ackerman et al. 1992). Nourished beaches tend to have a higher percentage of water content and tend to have darker sand color, which retains more light energy, leading to warmer sand temperatures. This effect is diminished over time as the nourished beach evolves and the sun bleaches the new sand to a color that gradually resembles that of a native beach (Lucas 2000).

Environmental variables (e.g., air temperature, sea surface temperature, precipitation) are often highly correlated, which can make the effect one a single variable difficult to isolate (Pike 2008b). Schwartz (1982) and Mortimer (1990) examined what role sediment grain size contributes to the microclimate. These studies reported greater hatching success occurred in medium- to fine-grain sands (0.125-0.25 mm) when compared to coarse sand (0.5-1.0 mm). Utilizing fill material resembling the natural sediment with respect to grain size and composition (e.g., < 10 percent fines and < 5 percent gravel/cobbles) can limit or eliminate negative impacts to the microclimate. Roe et al. (2013) found that leatherback turtles nesting was positively correlated to sand with a particle size of 0.025-mm diameter, but negatively correlated with sand in the smallest silt size class (<0.0625 mm diameter). Reasonable and prudent measures outlined in the Statewide Programmatic Biological Opinion have been adopted to resource sand with high compatibility to sand originally present or to sand found nearby (USACE 2015 a, 2010).

Excessive rainfall and high sand temperatures can disturb the nest microclimate. A nourished beach could potentially be affected by excessive rainfall if the design profile and sediment characteristics differed significantly from the beach that previously existed. Inundation from rainfall reduces ventilation and gas exchange, causing developing embryos and unemerged hatchlings to suffocate from limited oxygen supply (Patino-Martinez et al. 2014; Best 2017). However, too little precipitation can cause the embryos to overheat and perish or the nests to collapse entirely (Valverde et al. 2010; Saba et al. 2012). Warmer nest temperatures increase the rate of embryonic development, increase mortality, and produce large hatchlings (Kuroyanagi and Kamezaki 1993; Ackerman 1997; Broderick et al. 2001; Godley et al. 2001). Abnormally warm nest temperatures have been linked to reduced hatching success by as much as 50% given that higher nest temperatures increase the metabolic rate. This reduces the length of the incubation period and the amount of yolk able to be convert to hatchling tissue (Mazaris et al. 2009; Booth and Evans 2011; Sabra et al. 2012). Increases in sediment temperature on nourished beaches are related to darker sand color and a higher percentage of water content (Ackerman et al. 1992; Trindell et al. 1998). Ackerman et al. (1992) examined hatching success during progression of the nesting season on nourished beaches. As sand temperatures increased through the summer months, hatching success decreased. However, Trindell et al. (1998) reported no significant impacts to hatching success rate on nourished beaches.

2.6.10 Sediment moisture content

Viable hatchlings are produced by exchanging moisture during early incubation with the surrounding environment in the form of water vapor and possibly liquid water. Previous studies of marine turtles indicated the hydric environment can possibly affect various aspects of embryonic development including incubation time, residual yolk size, and hatchling size (Ackerman et al. 1992; Ackerman 1997; Tucker et al. 1998). Pike (2008b) found that the number of nests established in Central Florida was associated with rainfall. Rainfall, especially early in the incubation period, typically leads to a higher number of males produced. Later in the nesting season, no significant effect of cooling on sand temperature and subsequent higher number of males was observed (Lolavar and Wyneken 2015). McGehee (1990) reported the hatchling success of *Caretta* eggs was significantly affected by the moisture content of the sand used for incubation. Loggerhead eggs were divided into subsamples and incubated in sand containing one of five percentages of moisture (0, 25, 50, 75 and 100%). McGehee stated that a moisture level of 25% was the optimum level for maximum percent hatching and hatchling survival. Both dry and extremely wet conditions are associated with decreased hatching success and the average moisture content of the silica sand in natural nests of *Caretta* should be around 18%.

The egg water exchange is driven by the difference in water potential between the interior of the egg and the hydric environment of the surrounding beach. Water content and water potential of a beach depends on the type, size, and sorting of sand grains. More coarsely textured sediments will hold water less tightly than finely textured sands. This phenomenon may account for lower hatching success on coarse grained beaches (McGehee 1990). Mortimer (1990) reported clutch mortality is highest at beaches with low substrate water potential. In his study, he found a higher mortality in drier nesting conditions, particularly for green sea turtle eggs, which may be particularly sensitive to desiccation.

Özdemir and Türkozan (2006) examined the hatching success of natural and hatchery nests of green turtles in Northern Cyprus and found that nest depth was positively correlated with clutch size and moisture content. For both nests, the hatchling success was negatively affected by moisture content of the sand although there was a relatively weak relationship between the variables. For loggerhead turtles, Broadwell (1991) and Huerta (1995) found a positive correlation between moisture and hatching success. Mortimer (1990) stated that moisture may affect hatchling size and hatchling performance since survival was lowest for green turtle clutches at Ascension Island for nest laid in the driest substrata. Milton et al. (1997) reported no significant difference in hatchling success or emergence success when comparing silica sand (typical of US beaches) and aragonite sand. He concluded that although there were differences in the grain shape (silicia = rough; aragonite = ovoid), there was no difference in water potential available to the nest. Besides particle shape, the only other difference was in sand temperature. While nourished beaches are reported to retain 4 % more water than natural beaches, the water potentials of nourished and natural beaches are usually similar or identical (Rimkus 1992; Parkinson and Perez-Bedmar 1994; Ackerman 1997). Broadwell (1991) found the increased moisture in nourished beaches leads to an increase in hatchling emergence success and hatchling fitness. However, Wood and Bjorndal (2000) found no correlation between temperature, moisture and salinity, and the hatching success of loggerhead turtles near Melbourne Beach, FL. However, it was concluded that due to the sparse number of studies related to moisture content and nest success, questions are still raised as to the potential for increased risk to sea turtle nests from elevated moisture content and heat capacity (temperature buffer).

The role of sand moisture content during incubation on the post-emergence growth rates of loggerhead turtles was examined by Erb et al. (2018). Clutches receiving both ambient rainfall and a daily watering (wet treatment) had a larger initial size and grew at a greater rate than those emerging from the dry treatment (only ambient rainfall). Erb et al. (2018) hypothesized that the faster growth would allow turtles to reach a refuge size from their gape-limited predators.

2.6.11 Respiratory gas diffusion

Gas diffusion in a sea turtle nest is affected by water content (e.g., heavy rainfall) and particle size of the sand (Prange and Ackerman 1974; Kraemer and Bell 1980; Ackerman 1991). Ehrhart (1995) thought that substrates containing more moisture have reduced space between the sand grains which impedes gas exchange between the eggs and the sand pore water. Clutch oxygen consumption rates are related to clutch metabolic mass and the developmental stage (Ackerman 1980). It appears the number of hatchlings produced relative to eggs deposited by a female sea turtle is related to nest gas exchange. Factors acting to impair gas exchange within natural nests would prolong the exposure of the eggs to predators and the uncertainties of weather, disturb the synchrony of hatching, increase egg mortality, and generally lower the effectiveness of incubation in the beach (Ackerman 1980). Female sea turtles can influence the gas exchange within their clutch by the appropriate construction of the nest and ovipositing an appropriate metabolic mass in the nest (Ackerman 1975, 1980, 1997). During incubation, each egg exchanges heat, water, oxygen, and carbon dioxide with others in the clutch and the sediment surrounding the clutch (Ackerman 1997). Osmosis controls the egg water exchange and diffusion and is the principal mechanism for egg gas exchange. Because nourished beaches frequently have higher moisture content than natural beaches, nourished beach fill might have fewer available spaces between the grains and lower gas permeability than natural beach material. However, Broadwell (1991) and Steinitz et al. (1998) found that increased pore spacing led to better gas exchange between the nest and beach sediment on the nourished beach, as opposed to the natural control beach. Studies have shown that sea turtle eggs are sensitive to altered respiratory gas exchange, but no studies have addressed the impacts of altered egg gas exchange because of beach nourishment to embryonic development and hatching success.

2.6.12 Nest temperature

Sea turtles have their sex determined by nest temperature during embryonic development (Standora and Spotila 1985; Spotila et al. 1983, 1987). The internal microclimate of each nest is delicately balanced and can easily be influenced by external environmental conditions (Best 2017). Geographic location, beach orientation, nesting time within the nesting season, sand type and color, grain size, moisture content, and the degree of shade the nest experiences during incubation are all factors influencing nest temperature (Limpus et al. 1983; Milton et al. 1997; Hays 2001; Booth and Astill 2001; Mihnovets 2003; Mihnovets and Godfrey 2004). LeBlanc and Wibbels (2009) and Wyneken and Lolavar (2015) suggest the hydric environment combined with the thermal environment greatly influences the sex in sea turtles, but the influence of environmental factors during incubation on post-emergence development of hatchling sea turtles is mostly unknown. Metabolic heating by the developing embryos can also affect nest temperature (Broderick et al. 2001; Booth and Freeman 2006). Incubation temperatures not only affect sex, but also emergence success, morphology, and locomotor performance of hatchlings. Females need warmer temperatures to develop; green turtles need temperatures of 88^{o} F (31.1^{o} C) to develop into females, and temperatures around 82^{o} F (27.8^{o} C) are needed for male development. Temperatures between these values will produce a mixture of both. Sex is determined by sand temperature during the middle third of the incubation period (Mrosovsky and Pieau 1991). Stoneburner and Richardson (1981) found that loggerheads deposited their eggs in areas of elevated sand temperature, frequently in clumps close to vegetation.

Hawkes et al. (2007), Mrosovsky and Godfrey (2010), Fuentes and Cinner (2010), and Fuentes et al. (2011) have cited climate change as the reason for increasing nest temperatures which could skew the sex ratios of females to males. This will also contribute to the frequency of beach nourishment projects through increased storm intensity leading to extensive beach erosion (Hernandez 2014). Climate change can also negatively impact sea turtles by reducing the amount of dry beach available for nesting. The ability of sea turtles to adapt will depend, in part, on effective conservation and management strategies (Hamann et al. 2010).

Booth and Astill (2001) monitored temperatures at four locations within individual green sea turtle nests on Heron Beach and Great Barrier Island, throughout incubation. This was done to determine whether significant thermal differences existed within a nest and to see if egg location within the nest was likely to be a significant factor in determining hatchling sex. They reported small differences between regions of a nest persisting throughout the incubation period ensuring at least some individuals of the opposite sex would be produced and neither shading of the nest nor nest location had any effect on mean nest temperature. Some differences in temperature were attributed to nest depth since the bottom of a green turtle nest is approximately 30 cm deeper than the top. Sim et al. (2015) examined nest temperature on hatchling and emergence success and found a decrease in both when nest temperatures exceeded 34°C compared to nests with temperatures lower than 34°C. Smaller hatchlings associated with higher incubation temperatures have also been reported by Reece et al. (2002), Booth and Freeman (2006), and Burgess et al. (2006). Neither study was conducted on nourished beaches.

Some studies suggest that for some nourished beaches, changes in beach temperature may not be as great as natural beaches due to the higher water content and the higher heat capacity (heat storage) of water. Although temperature is a critical factor in the success of sea turtle nests, few studies exist investigating the thermal properties of nourished beaches. Temperature differences, between natural and nourished beaches, typically range from 0.5° to 2.0° C (Lutcavage et al. 1997). Wood and Bjorndal (2000) found sand temperature did not appear to be a major cue to sea turtles to select or reject nesting sites, whereas Stoneburner and Richardson (1981) previously found it to be an important factor. Fluctuations in internal nest temperatures naturally occur during incubation and serve as critical factors during the embryonic development of sea turtles. However, due to the potential for higher heat capacity on nourished beaches, these nests may show less change in nest temperature than on natural beaches (Ackerman 1994; Ackerman 1997).

Changes to normal nest temperatures may influence the egg water exchange and duration of incubation (Milton et al. 1997). Warmer temperatures associated with darker beach fill have been known to decrease the incubation period, where cooler temperatures from lighter-color sand (e.g., aragonite) cause significantly longer incubation times (Schulman et al. 1994). Since the number of nourishment projects has increased over the past several decades and offshore sand resources have decreased, Milton et al. (1997) examined the effect of beach nourishment with aragonite versus silicate sand on beach temperature and loggerhead nesting success. While both sand types had similarly high hatching and emergence success rates of 86% to 97%, the study raised important questions concerning the possible effects of nest temperatures on hatchling sex ratios. Sand temperature in aragonite sand ranged from around one degree to as much as 3.4^{o} C cooler than silicate sand at identical depths, which could alter natural sex ratios by producing male-biased hatchling sex ratios. Nest incubation temperatures determine hatchling gender with more males produced at low temperatures ($\leq$ 28^{o}C) and females produced at high temperatures ($\geq$ 32^{o}C) (pivotal 29^{o}C) (Spotila et al.1983; Mrosovsky and Provancha 1992; Mrosovsky 1994; Booth and Astill 2001; Spotila 2004). Pivotal temperatures for the leatherback, green, and hawksbill turtles are reported near the 28-30^{o} C range. While very few data are available characterizing beach temperatures in sea turtle nests, ambient nest temperature on nourished beaches could directly impact hatchling sex ratios if nourished sediment differs significantly from that found on natural nesting beaches.

Since the issue of temperature in determining hatchling sex ratios has been recognized, Flynn (2012) suggested that sea turtles find suitable nesting sites by determining the temperature of the sand, perhaps by females using their skin temperature. Data collected in this study assessed temperature readings within crawl tracks of turtles that successfully nested as well as those that false crawled. Flynn (2012) found a significant difference in temperature collected within the tracks of false crawl events and nest events. It was also reported that other loggerhead rookeries in the US and Australia yielded similar results.

2.7 Mitigating impacts

2.7.1 Active construction hazards

In Florida, environmental regulations for construction permits typically restrict nourishment activities from 15 May through 15 October, however, dates may vary for other states due to regional nesting differences. Most incidental takes and disturbances can be avoided by conducting beach nourishment and hopper dredging activities outside of turtle nesting season or times of peak turtle abundance (Crain et al. 1995; Dickerson et al. 2004). When nourishment projects must occur during the nesting season, monitoring for potential nest locations is requisite. As practicable: (1) locate temporary equipment staging areas off the beach or as far landward as possible without compromising the dune integrity; (2) position sand-placement pipelines bypassing any existing nests and place stockpiled pipes landward and perpendicular to the shore impacting the least amount of nesting habitat; and (3) limit operation of heavy equipment within the project area to daylight hours in order to minimize impacts to nighttime nesting and hatchling activities, while maintaining compliance with all safety requirements.

Light disorientation impacts should be monitored and minimized by reducing the wattage of light sources, altering the direction of light sources by shielding or lowering the light elevation, and using lights with spectral properties (longer wavelengths) that are less disruptive to sea turtles. Shielded low-pressure sodium-vapor lights have been identified by the FDEP as the best commercially available lights that balance human safety with successful sea-finding behavior for turtles (Witherington and Martin 2003; Gallagher 2006).

When beach nourishment projects must occur during the nesting season, priority should be on reducing or eliminating impacts on nests before implementing nest relocation. However, in cases such as severe erosion following hurricanes or other emergency situations, nourishment projects may occur during the nesting season with a stipulation that nests be relocated to protected areas.

2.7.2 Nesting beach habitat factor

Initially, the beach profile was not considered in the project design with respect to sea turtle nesting requirements; however, it is now considered an important factor. Beach profile design, especially width and slope, should mimic that of the natural beach whenever possible maximizing quality nesting habitat available to turtles. Armoring the beach with hard structures should be done conservatively. While natural beach parameters may also provide more effective shore protection from storm surge and wave action, identifying the historic natural beach conditions can be challenging due to many years of beach development (Coastal Engineering Research Center 1984; National Research Council 1995; Dean 2002).

Although escarpments will normally disappear as the physical dynamics of the beach assumes a natural profile, equipment can be used to smooth escarpments interfering with sea turtle nesting (e.g., escarpments exceeding 18 in. high and 100 ft long) before onset of the nesting season or during the nesting season under the direction of the USFWS. Since escarpments occur naturally on all beaches, it may be futile to attempt eliminating all escarpments post-nourishment.

2.7.3 Nest microhabitat requirements

Sand proposed for a nourishment project should closely match the natural sediment type and size, organic content, color, and other sediment features to compensate for a lack of information regarding potential changes in moisture content, gas diffusion, and temperature variation. Utilizing natural sediment parameters may also reduce the need to till nourished beaches. No guidance is currently available for required or minimal levels of nutrients, minerals, or environmental contaminants for normal sea turtle egg development.

3 Conclusions

Currently, beach nourishment is the most acceptable engineering solution for protecting coastal development and restoring sea turtle habitat after storm induced erosion. However, there is a need to properly balance both the requirement to protect coastal property and shorelines and the conservation of sea turtle populations. Research has shown that the principal effect of sand placement on sea turtle reproduction is a reduction in nesting success, which is most often limited to the first year following project construction. It has also shown that the impacts of a nourishment project on sea turtle nesting habitat are typically short-term because a nourished beach will be reworked by natural processes in subsequent years, and beach compaction and the frequency of escarpment formation will decline. Although a variety of factors influence how a nourishment project will perform from an engineering perspective, measures can be implemented to minimize impacts to sea turtles. These “reasonable and prudent measures” were established by the USFWS in conjunction with other agencies to minimize impacts on sea turtle reproduction.

3.1 Beach nourishment impacts

Beach nourishment projects in the Southeastern US can potentially affect sea turtles directly or indirectly in the following ways.

1. Hopper dredges may entrain adults and sub-adults during excavation of sediment.
2. Construction activities and equipment can deter nesting, prevent access to nesting beaches, destroy nests, or harm nesting females or hatchlings.
3. Artificial lighting may disorient nesting females and hatchlings.
4. Nest relocation may reduce hatching success. Relocation may congregate eggs in an area making them more susceptible to catastrophic events and can also lead to higher predation rates by land and marine predators.
5. Beach armoring with hard structures may prevent access to suitable nesting sites, impede and/or trap nesting females and hatchlings, and increase clutch mortality due to frequent inundation.
6. Increased beach shear resistance and compaction may prevent successful nest construction and contribute to increased nest predation.
7. Escarpment formations may impede nesting attempts.

8. Changes to microclimate conditions may influence nest site selection, nesting success, duration of incubation, hatchling sex ratios, and hatching success.

3.2 Minimizing beach nourishment impacts

Beach nourishment impacts to sea turtles may be minimized or alleviated by implementing the actions listed below when possible. These actions are considered "reasonable and prudent" and are covered in the Statewide Programmatic Biological Opinion (USFWS 2015a, b) for the State of Florida and are mandated by the USFWS for all major beach nourishment projects. Other states with beaches that have nesting turtles follow similar measures to protect sea turtle nesting activities (e.g., North Carolina Coastal Beach Sand Placement Statewide Programmatic Biological Opinion 2017). If any of these requirements cannot be fulfilled, USACE must reinitiate consultation with the USFWS.

1. All conservation measures included in the Statewide Programmatic Biological Opinion (2015a) addressing protection of nesting sea turtles shall be implemented in Federally authorized projects or regulated activities.
2. Sand placement shall not occur during the period of peak sea turtle egg laying and egg hatching to reduce the possibility of sea turtle nest burial, crushing of eggs, or nest excavation. Although dates can vary by region, nourishment projects shall be started after October 31st and completed before May 1st.
3. Beach quality sand suitable for sea turtle nesting, successful incubation, and hatchling emergence shall be used for nourishment projects. Beach compatible fill is material maintaining the general character and functionality of the material occurring on the beach and in the adjacent dune and coastal system.
4. All derelict material or other debris shall be removed from the beach prior to any sand placement.
5. The beach profile template for the sand placement project shall be designed to mimic the native beach berm elevation and beach slopes landward and seaward of the equilibrated berm crest.
6. If a dune system is part of the project design, sediment material must be placed and designed to emulate the natural dune system to the maximum extent possible, including the dune configuration and shape.

7. Predator-proof trash receptacles shall be installed and properly maintained at all beach access points to minimize the potential for attracting predators of sea turtles.
8. If the nourishment project will be conducted during sea turtle nesting season, surveys for nesting sea turtles must be conducted by a Florida Fish and Wildlife Conservation Commission (FWC)-authorized Marine Turtle Permit Holder. Surveys for early and late nesting sea turtles shall be conducted where appropriate. Any known nests recorded just prior to the beginning of nesting season monitoring must be relocated if it will be impacted by the construction activity or marked and avoided if feasible.
9. If nests are constructed around proposed sand placement, the eggs shall be relocated to minimize sea turtle nest burial, crushing of eggs, or nest excavation. Relocated nests shall be randomly staggered along the length and width of the beach in locations not expected to experience daily inundation by high tides or known to routinely experience severe erosion and egg loss and predation. For sand placement projects occurring during the period from November 1st through the end of hatching season, daily early morning sea turtle nesting surveys shall be conducted 65 days prior to project initiation and continue through mid-November.
10. A post construction survey(s) of all artificial lighting visible from the project beach shall be completed by the Applicant or the USACE.
11. Daily nesting surveys will be conducted by an approved FWC Marine Turtle Permit Holder for two nesting seasons following construction if the new sand remains on the beach. Post-construction Year 1 surveys shall record the number of nests, nesting success, reproductive success, disorientations, and lost nests due to erosion and/or inundation. Post-construction Year 2 surveys shall record nest number, nesting success, and disorientations.
12. Sand compaction shall be monitored, and tilling conducted if needed to reduce the likelihood of impacting sea turtle nesting and hatching activities.
13. Escarpment formation shall be monitored and leveling shall be conducted if needed to reduce the likelihood of impacting nesting and hatchling sea turtles.
14. Construction equipment and materials including pipes shall be stored off the beach in a manner that will minimize impacts to nesting and hatchling sea turtles.
15. Lighting associated with the project construction, including on the dredge, shall be minimized to reduce the possibility of disrupting and disorienting

nesting and hatchling sea turtles. The impact of light on nesting females and hatchlings can be minimized by reducing the number of wattages of light sources by modifying the direction of light sources through shielding, redirection, or modification in the height of the lighting source.

16. During sea turtle nesting season, the USACE shall not extend the beach fill more than 500 ft between dusk and the time of completion of the following day's nesting survey to reduce the impact to emerging sea turtles and burial of new nests.
17. All vegetation planting shall be designed and conducted to minimize impacts to sea turtles. No dune planting activity shall occur until after the daily turtle survey has been completed (9 a.m.). Turtle nests identified during planting will be marked and a 3-ft perimeter will be established where no planting will occur. All dune planting will occur by hand and only during daylight hours and must consist of species native to the local area.
18. Existing vegetated habitat at beach access points and travel corridors shall be protected to the maximum extent possible to ensure vehicles and equipment transport stay within the access corridor.
19. The USFWS and the FWC shall be notified if a sea turtle adult, hatchling, or egg is harmed or destroyed as a direct or indirect result of the project.

To understand how best to design beach nourishment projects that minimize impacts to sea turtles, adequate information on sea turtle biology must be known. Over the last several decades, researchers have completed many studies examining the effects of beach nourishment on various aspects of sea turtle reproduction. However, many of these studies have addressed the issue on a relatively short-term basis, mostly through graduate thesis projects. The US Fish and Wildlife Service has placed conditions on beach nourishment projects to minimize the impacts on sea turtle reproduction, such as nest relocation, the use of beach quality sand, management of project lighting, and the monitoring of sand compaction and escarpment changes. Significant improvements have been achieved in these areas to minimize impacts to sea turtles.

Although more is known now about sea turtle nesting and beach nourishment, many studies regarding the benefits or detriments of nourishment are either inconclusive or contradictory. There is little doubt that nourishment of a severely eroded beach, mostly devoid of sand and sea turtle nesting habitat, will benefit greatly from nourishment. Beaches less severely eroded, but undergo renourishment, will typically see a reduction in nesting activity during the first year of post-sand placement. With sea level rise and the increasing threat of more severe storms, beach nourishment projects will likely increase in frequency and scale over the next several decades, much like they have done over the last 5 decades. These projects have been employed to restore and maintain many beaches where erosion had critically threatened or eliminated habitat for threatened and endangered species, i.e., sea turtles, piping plover (*Charadrius melodus*), and numerous plant species. The protection and preservation of habitat has allowed beach restoration projects to become useful conservation techniques for coastal ecosystem management. Adhering to the "Reasonable and Prudent" measures developed will aid in protecting species at risk. With sufficient knowledge of sea turtle environmental requirements and appropriate application of that knowledge, beach nourishment has the potential to be a valuable conservation technique for restoring sea turtle nesting habitat and providing protection and enhancement of coastal development.

References

Ackerman, R. A. 1975. *Diffusion and the gas exchange of sea turtle eggs*. Ph.D. Dissertation. Gainesville, FL: University of Florida. http://ufdc.ufl.edu/AA00047545/00001

Ackerman, R. A. 1980. "Physiological and ecological aspects of gas exchange by sea turtle eggs." *American Zoology* 20: 575-583.

Ackerman, R. A. 1991. Physical factors affecting the water exchange of buried reptile eggs. *In*: *Egg incubation. Its effects on embryonic development in birds and reptiles*, Demming D.C., Ferguson, M.W.J., editors. Cambridge: Cambridge University Press. pp. 83-106.

Ackerman, R.A. 1994. "Temperature, time, and reptile egg water exchange." *Israel Journal Zoology* 40: 293-306. Ackerman, R. A. 1997. The respiratory gas exchange of sea turtle nests (Chelonia Caretta). *Resp. Physiol.* 31: 19-38.

Ackerman, R. A. 1997. "The respiratory gas exchange of sea turtle nests (*Chelonia caretta*)." *Resp. Physiol.* 31:19-38.

Ackerman, R. A. 1997. "The nest environment and the embryonic development of sea turtles." Pages 83-106 *In*: Lutz, P.L. and J.A. Musick (editors). *The Biology of Sea Turtles*. Boca Raton, FL: CRC Press.

Ackerman, R. A., T. Rimkus, and R. Horton. 1992. *The hydric structure and climate of natural and renourished sea turtle nesting beaches along the Atlantic Coast of Florida*. Report to Florida Department of Natural Resources, Contract #6407.

Allen, C. R., E. A. Forys, K. G. Rice, and D. P. Wojcik. 2001. "Effects of fire ants on hatchling sea turtles and the prevalence of fire ants on sea turtle nesting beaches in Florida." *Florida Entomology*, 84:250-253.

Ahles, N. M., and S. L. Milton. 2016. "Mid-incubation relocation and embryonic survival in loggerhead sea turtle nests." *Journal of Wildlife Management*. 71:2290.

ASTM. 2006. *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*. D 2487-06. 12 pp.

Banks, G. E., and M. P. Alexander. 1994. *Development and evaluation of a sea turtle-deflecting hopper dredge draghead*. Miscellaneous Paper HL-94-5. Vicksburg, MS: US Army Corps of Engineers.

Barshel N., R. Bruce, C. Grimm, D. Haggitt, B. Lichter, and J. McCray. 2014. *Sea turtle friendly lighting. A model ordinance for local governments*. Gainesville, FL: Levin College of Law, Conservation Clinic, University of Florida.

Baskale, E., and Y. Kaska. 2005. "Sea turtle nest conservation techniques on southwestern beaches in Turkey." *Israel Journal of Zoology* 51:13-26.

Beatley, T., D. J. Brower, and A. K. Schwab. 2002. *An Introduction to Coastal Zone Management*. Washington, DC: Island Press, 285p.

Berry, M., and D. T. Booth. 2013. “Artificial lighting and disrupted sea-finding behaviour in hatchling loggerhead turtles (*Caretta caretta*) on the Woongarra coast, south-east Queensland, Australia.” *Australian Journal of Zoology* 61(2):137.

Best, Z. E. 2017. Environmental factors affecting loggerhead sea turtle (*Caretta caretta*) nesting, hatching, and incubation patterns in Broward County, Florida. MS Thesis, Nova Southeastern University.

Booth, D. T., and K. Astill. 2001. “Temperature variation within and between nests of the green sea turtle, Chelonia mydas (Chelonia: Cheloniidae) on Heron Island, Great Barrier Reef.” *Australian Journal of Zoology* 49: 71-84.

Booth, D. T., and A. Evans. 2011. “Warm water and cool nests are best. How global warming might influence hatchling green turtle swimming performance.” *PLoS ONE* 6(8):e23162. Doi:10.1371/journal.pone.0023162.

Booth, D. T., and C. Freeman. 2006. “Sand nest temperatures and an estimate of hatchling sea ratio from the Heron Island green turtle (*Chelonia mydas*) rookery. Southern Great Barrier Reef.” *Coral Reefs* 25: 629-633

Bouchard, S., K. Moran, M. Tiwari, M. Wood, A. Bolten, P. Eliazar, and K. Bjorndal. 1998. “Effects of exposed pilings on sea turtle nesting activity at Melbourne Beach, Florida.” *Journal of Coastal Research*, 14, 1346-1347.

Boulon, R. H. 1999. Reducing threats to eggs and hatchlings: *in situ* protection. In *Eckert, K.L., Bjorndal, K. A. Abreu-Grobois, F. A., and Donnelly, M. (Eds.). Research and Management Techniques for the Conservation of Sea Turtles. Washington, DC: International Union for the Conservation of Nature/Species Survival Commission Marine Turtle Specialist Group Publication No 4, pp. 169-174.*

Bourgeois, S., G. F. Emmanuelle, A. Viallefront, F. Boussamba, and S. L. Deem. 2009. “Influence of artificial lights, logs and erosion on leatherback sea turtle hatchling orientation at Pongara National Park, Gabon.” *Biological Conservation* 142:85-93.

Brig, C. E. 2014. Assessment of Loggerhead Sea Turtle (Caretta caretta) Nest Management Tools in South Carolina. MS Thesis, Clemson University.

Broadwell, A.L. 1991. Effects of beach renourishment on the survival of loggerhead sea turtle nests. MS Thesis, Florida Atlantic University.

Brock, K. 2005. Effects of a shore protection project on loggerheads and green turtle nesting activity and reproduction in Brevard County, Florida. MS Thesis, University of Central Florida.

Brock, K. A., J. S. Reece, and L M. Ehrhart. 2007. “The effects of artificial beach nourishment on marine turtles: Differences between loggerheads and green turtles.” *Restoration Ecology* 17(2): 99.297-307.

Broderick, A. C., B. J. Godley, and G. C. Hays. 2001. “Metabolic heating and the prediction of sea ratios for green turtles (*Chelonia mydas*).” *Physiol. Biochem. Zool*, 74: 161-170.

Burgess, E. A., D. T. Booth, and J. M. Lanyon. 2006. “Swimming performance of hatchling green turtles is affected by incubation temperature.” *Coral Reefs* 25: 341-349.

Burney, C., and C. Mattison. 1992. The effects of egg relocation and beach nourishment on the nesting and hatchling success of *Caretta caretta* in Broward County, Florida, 1991. In *Proceedings of the fifth annual National Conference on Beach Preservation Technology: New Directions in Beach Management*, pg 395-407. Tallahassee, FL: Florida Shore and Beach Preservation Association.

Bush, D. M., W. J. Neal, N. J. Longo, K. C. Linderman, D. F. Pilkey, L. S. Esteves, J. D. Congleton, and O. H. Pilkey. 2004. *Living with Florida’s Atlantic Beaches: Coastal Hazards from Amelia Island to Key West*. Duke University Press, 360p.

Byrd, J. I. 2004. The effect of beach nourishment on loggerhead sea turtle (*Caretta caretta*) nesting in South Carolina. MS Thesis, College of Charleston.

Candan, O. 2017. “Impact of nest relocation on the reproductive success of Loggerhead Turtles, *Caretta caretta*, in the Göksu Delta, Turkey.” *Zoology in the Middle East*, 64: 38-46.

Carthy, R. 1994. Loggerhead nest morphology: effects of female body size, clutch size, and nesting medium on nest chamber size. In *Proceedings of the fourteenth annual Symposium on Sea Turtle Biology and Conservation*, pg 25-27. National Oceanographic and Atmospheric Administration Technical memorandum NMFS-SEFC-351.

Caut, S., E. Guirlet, and M. Girondot. 2010. “Effect of tidal overwash on the embryonic development of leatherback turtles in French Guiana.” *Marine Environmental Research* 69: 254-261.

Cisneros, J. A., T. R. Briggs, and K. Martin. 2017. “Placed sediment characteristics compared to sea turtle nesting and hatchling patterns: A case study from Palm Beach County, FL.” *Shore and Beach* 85(2) 35-40.

Clarke, R. 1993. *Beach Conditions in Florida: A Statewide Inventory and Identification of the Beach Erosion Problem Areas in Florida* in Florida Department of Environmental Protection. 5th Edition, December 1993. Beaches and Shores Technical and Design Memorandum 89-1.

Coastal Engineering Research Center. 1984. Shore Protection Manual Volume I. Vicksburg, MS: USACE Waterways Experiment Station.

Coll, G. E. 2010. Sea turtle nest management: Examining the use of relocation as a management tool on three South Carolina beaches. MS Thesis, College of Charleston.

Crain, D. A., A. B. Bolton, and K. A. Bjorndal. 1995. "Effects of beach nourishment on sea turtles: review and research initiatives." *Restoration Ecology* 3: 95-104.

Dallas, K. L., J. Eshleman, and R. Beavers. 2012. *National Park Service beach nourishment guidance*. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2012/581. Fort Collins, CO: National Park Service.

Davis, Jr., D. A., M. V. FitzGerald, and J. Terry 1999. "Turtle nesting on adjacent beaches with different construction styles: Pinellas County, Florida." *Journal of Coastal Research*. 15: 111-120.

Davis, P., B. Howard, S. Derheimer, R. Bishop, J. Biery, T. Potter, and N. Blackson. 2002. "A preliminary look at sediment re-compaction throughout the nesting season on a nourished beach at Ocean Ridge, Palm Beach County, Florida, USA." In *Proceedings of the 20th annual Sea Turtle Symposium on Sea Turtle Biology and Conservation*, pg 330. National Oceanographic and Atmospheric Administration Technical Memorandum NMFS-SEFSC-477.

Dean, R. G. 2002. "Beach nourishment: theory and practice." *Advanced Series on Ocean Engineering*, 18, 420.

Defeo, O., A. McLachlan, D. S. Schoeman, T. A. Schlacher, J. Dugan, A. Jones, M. Astra, and F. Scapini. 2009. "Threats to Sand Beach Ecosystems: A Review." *Estuarine, Coastal and Shelf Science* 81:1-12.

Dellert, L. J., D. O'Neil, and D. L. Cassill. 2014. "Effects of beach renourishment and clutch relocation on the success of the loggerhead sea turtle (Caretta caretta) eggs and hatchlings." *Journal of Herpetology* 48(2):186-187.

Dickerson, D. D., M. S. Wolters, C. T. Theriot, and C. Slay 2004. "Dredging impacts on sea turtles in the Southeastern USA: A historical review of protection." In *Proceedings of World Dredging Congress XVII, Dredging in a Sensitive Environment*. 27 September-1 October 2004, Central Dredging Association, ISBN 90-9018244-6, CD-ROM.

Dodd, C. K. J. 1988. *Synopsis of the biological data on the loggerhead sea turtle Caretta caretta (Linnaeus 1758)*. US Fish and Wildlife Service, Biological Report 88-14, pp.110.

Dugan, J. E., D. M. Hubbard, L. F. Rodil, D. L. Revell, and S. Schroeter. 2008. "Ecological effects of coastal armoring on sand beaches." *Marine Ecology*, 29(Suppl. 1), 160-170.

Dutton, D. L., P. H. Dutton, M. Chaloupka, and R. H. Boulon. 2005. "Increase of a Caribbean leatherback turtle *Dermochelys coriacea* nesting population linked to long-term nest protection." *Biological Conservation* 126:186-194.

Erb, V. A. Lolavar, and J. Wyneken. 2018. "The role of sand moisture in shaping loggerhead turtle (*Caretta caretta*) neonate growth in southeast Florida." *Chelonian Conservation and Biology* 17(2):245-251.

Eckert, K. L., and S. A. Eckert. 1990. "Embryo mortality and hatch success in *in situ* and translocated leatherback sea turtle *Dermochelys coriacea* eggs." *Biological Conservation* 53:37-46.

Ehrhart, L. M. 1995. *The relationship between marine turtles nesting and reproductive success and the beach nourishment project at Sebastian Inlet, Florida, in 1994*. Technical Report to the Florida Institute of Technology, pg. 1-55. Melbourne, Florida.

Ernest, R. G., and R. E. Martin. 1993. *Sea turtle protection program performed in support of velocity cap repairs, Florida Power and Light Company St. Lucie Plant*. Jensen Beach, FL: Applied Biology Inc.

Ernest, R. G., and R. E. Martin. 1999. *Martin County beach nourishment project: Sea turtle monitoring and studies. 1997 annual report and final assessment*. Jensen Beach, FL: Applied Biology, Inc.

Ernest, R. G., R. E. Martin, B. Howard, and A. M. Black. 1995. "The effect of beach nourishment on sea turtle nesting: A case study on Hutchinson Island, Florida." In *Proceedings of the Coastal Ecosystems and Federal Activities Technical Training Symposium*, August 20-22, 2001, pg. 93-108.

Farley, P.P. 1923. "Coney Island public beach and boardwalk improvement." *The Municipal Engineers Journal* 9:136.1-136.32.

FDEP. 2019. *Beach management funding assistance program fixed capital outlay local government funding request, Fiscal Year 2019-2020*. Data Report. Division of Water Resource Management, Florida Department of Environmental Protection, Data Report, February 2019, 48 p.

Fish, M. R., I. M. Cote, J. A. Gill, A. P. Jones, S. Renshoff, and A. R. Watkinson. 2005. "Predicting the impact of sea-level rise on Caribbean Sea turtle nesting habitat." *Conservation Biology* 19: 482-491.

Fletemeyer, J.R. 1984. "The impact of beach renourishment on sea turtle nesting." In *The New Threat to Beach Preservation*, September 1983 joint annual meeting of the American Shore and Beach Preservation Association in Boca Raton, Florida.

Flynn, L. N. 2012. Thermal determinants of nest site selection in loggerhead sea turtles, *Caretta caretta*, at Casey Key, Florida. MS Thesis, College of Marine Science, University of South Florida.

Foley, A. M., S. A. Peck, and G. R. Harmann. 2006. "Effects of sand characteristics and inundation on the hatchling success of loggerhead sea turtle (*Caretta caretta*) clutches on low-relief mangrove islands in southwest Florida." *Chelonian Conservation and Biology* 5:32-41.

Foley, A. M., S. A. Peck, G. R. Harman, and L. W. Richardson. 2000. "Loggerhead turtle (*Caretta caretta*) nesting habitat on low-relief mangrove islands in southwest Florida and consequences to hatchling sex ratios." *Herpetologica* 56, 433-445.

Foote, J., S. Fox, and T. Mueller. 2002. "An unfortunate encounter with a concrete and rock composite groin." In *Proceedings of the Twentieth Annual Symposium on Sea Turtle Biology and Conservation*, 369 pp. NOAA Technical Memorandum NMFS-SEFSC-477.

Fuentes, M. M. P. B., and J. E. Cinner. 2010. "Using expert opinion to prioritize impacts of climate change on sea turtles' nesting grounds." *Journal of Environmental Management*, 91: 2511-2518.

Fuentes, M. M. P. B., C. L. Limpus, and M. Hamann. 2011. "Vulnerability of sea turtle nesting grounds to climate change." *Global Change Biology*, 17: 140-153.

Fuentes, M.M.P.B., C. L. Limpus, M. Hamann, and J. Dawson. 2010. "Potential impacts on sea-level rise on sea turtle rookeries." *Aquatic Conservation: Marine and Freshwater Ecosystems,* 20: 132-139.

Gallaher, A. A. 2009. The effects of beach nourishment on sea turtle nesting densities in Florida. Ph.D. Thesis. University of Florida.

Garmestani, A. S., H. F. Percival, K. M. Portier, and K. G. Rice. 2000. "Nest-Site Selection by the Loggerhead Sea Turtle in Florida's Ten Thousand Islands." *Journal of Herpetology,* 34(4):504

Glenn, L. 1998. "The consequences of human manipulation of the coastal environment on hatchling loggerhead sea turtles (*Caretta caretta*, L.)." In *Proceeding of the Sixteenth Annual Symposium on Sea Turtle Biology and Conservation*, pg. 58-59. NOAA Technical Memorandum NMFS_SEFSC-412.

Godley, B. J., A. C. Broderick, J. R. Downie, F. Glen, J. D. Houghton, I. Kirkwood, S. Reece, and G. C. Hays. 2001. "Thermal conditions in nests of loggerhead turtles: further evidence suggesting female skewed sex ratios of hatchling production in the Mediterranean." *Journal of Experimental Marine Biology and Ecology* 263:45-63.

Gravens, M., B. Ebersole, T. Walton, and R. Wise. 2008. "Beach fill design." In *Coastal Engineering Manual, Part V, Coastal Project Planning and Design, Chapter IV-4, Engineer Manual 1110-2-1100*, US Army Corps of Engineers.

Guilfoyle, M. P., J. F. Jung, R. A. Fischer, and D. D. Dickerson. 2019. *Developing Best Management Practices for Coastal Engineering Projects that Benefit Atlantic Coast Shoreline-dependent Species*. ERDC/TN EMRRP-SI-38. Vicksburg, MS: US Army Engineer Research and Development Center. http://el.erdc.usace.army.mil/emrrp/techran.html.

Hamann, H., M. H. Godfrey, and J. A. Seminoff. 2010. "Global research proprieties for sea turtles, informing management and conservation in the 21st century." *Endangered Species Research*, 11: 245-269.

Hawkes, L. A., A. C. Broderick, M. H. Godfrey, and B. J. Godley. 2007. "Investing the potential impacts of climate change on a marine turtle population." *Global Change Biology* 13: 923-932.

Hays, C. G. 2001. “The importance of sand albedo for the thermal conditions on sea turtle nesting beaches.” *Oikos* 93: 87-95.

Hays, G. C., A. Mackay, C. R. Adams, J. A. Mortimer, J. R. Speakman, and M. Boerema. 1995. “Nest site selection by sea turtles.” *Journal of the Marine Biological Association of the United Kingdom*, 75: 667-674.

Hays, G. C., and J. R. Speakman. 1992. “Nest placement by loggerhead turtles.” *Caretta caretta*, *Animal Behavior* 45: 47-53.

Hendrickson, J. R. 1995. “Nesting behavior of sea turtles with emphasis on physical and behavioral determinates of nesting success or failure.” In *Biology and Conservation of Sea Turtles*, pg. 53-57. Washington, D. C. Smithsonian Institution Press.

Hernandez, K. 2014. Protecting beaches and sea turtles: An analysis of beach nourishment in North Carolina, the impacts on nesting loggerhead sea turtles, and how sea level rise will transform the status quo. MS Thesis, Nicholas School of the Environment, Duke University.

Herren, R. M. 1999. The effect of beach nourishment on loggerhead (*Caretta caretta*) nesting and reproductive success a Sebastian Inlet, Florida. MS thesis, University of Central Florida.

Herren, R. M., J. C. Gorham, and J. D. Gray, Jr. 2007. “Comparison of loggerhead reproductive success in seawall nests and non-seawall nests in southern Indian River County, Florida, 2006.” In *Proceedings of the 28th International Sea Turtle Symposium (Myrtle Beach, South Carolina)*, pp. 236.

Hockert, W. E. J., H. G. van Tienen, P. van Nugteren, and S. Dench. 1998. “The ‘sea turtles of Suriname 1997’—project comparing relocated nests to undisturbed nests.” In *Proceedings of the Eighteenth International Sea Turtle Symposium. National Oceanic and Atmospheric Administration Technical Memorandum MFS-SEFSC-436,* pg. 192-193. Miami, FL.

Horrocks, J. A., and N. M. Scott. 1991. “Nest site location and nest success in the hawksbill turtle *Eretmochelys imbricate* in Barbados, West Indies.” *Marine Ecology Progress Series* 69: 1-8.

Hosier, P. E., M. Kochhar, and V. Thayer. 1981. “Off-road vehicle and pedestrian track effects on the sea-approach of hatchling loggerhead turtles.” *Environmental Conservation* 8:158–161.

Hu, Z., H. Hu, and Y. Huang. 2018. Association between nighttime artificial light pollution and sea turtle nest density along Florida coast: A geospatial study using VIIRS remote sensing data. *Environmental Pollution*, 239: 30-42.

Huerta, B. F. 1995. “Relationship between sand moisture and hatchling success of olive ridley (*Lepidochelys olivacea*), at Escobilla, Oaxaca.” In *Proceedings of the Twelfth Annual Workshop on Sea Turtle Biology and Conservation*, pg. 162-165. NOAA Technical Memorandum, 361.

Hughes, A. L., and E. A. Caine. 1994. "The effect of beach features on hatchling loggerhead sea turtles." In *Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation*, March 1–5, Hilton Head, SC. p. 237. National Oceanic and Atmospheric Administration, Technical Memorandum NMFS-SEFSC-351.

Hughes, G. R., A. J. Bass, and M. T. Mentis. 1967. "Further studies on marine turtles in Tongaland." *Lammergeyer,* 7: 4-54.

Ilgaz, C., and I. Baran. 2001. "Reproduction biology of the marine turtle population in Northern Karpaz (northern Cyprus) and Dalyan (Turkey)." *Zoology in the Middle East,* 24:35-44.

Ilgaz, C., A. Özdemir, Y. Kumlutaş, and S. H. Durmuş. 2011. "The effect of nest relocation on embryonic mortality and sea ratio of loggerhead turtles, *Caretta caretta* (Reptillia: Cheloniidae), at Dalyan Beach, Turkey." *Italian Journal of Zoology*, 78:354-363.

Johannes, R. E., and D. W. Rimmer. 1984. "Some distinguishing characteristics of the green turtle (*Chelonia mydas*) on North West Cape Peninsula, Western Australia." *Marine Biology,* 83:149-154.

Kamrowski, R. L., C. Limpus, R. Jones, S. Anderson, and M. Hamann. 2014. "Temporal changes in artificial light exposure of marine turtle nesting areas." *Global Change Biology,* 20: 2437-2499.

Karnard, D., K. Isvarab, C. S. Kar, and K. Shanker. 2009. "Lighting the way: Towards reducing misorientation of olive ridley hatchlings due to artificial lighting at Rushikulya, India." *Biological Conservation,* 142(10):2083-2088.

Kikukawa, A., N. Namezaki, K. Hirate, and H. Ota. 1998. "Factors affecting nest beach selection by sea turtles: A multivariate approach." In *Proceedings of the 17th Annual Symposium on Sea Turtle Biology and Conservation*, pg. 65-66. NOAA Technical Memorandum NMFS-SEFSC-415.

Kikukawa, A., N. Namezaki, K. Hirate, and H. Ota. 1999. "Factors affecting nesting beach selection by loggerhead turtles (*Caretta caretta*): A multiple regression approach." *Journal of Zoology,* 249: 447-454.

Klein, R. J. T., R. J. Nicholls, S. Ragoonaden, M. Capobianco, J. Aston, and E. N. Buckley. 2001. "Technological options for adaptation to climate change in coastal zones." *Journal of Coastal Research,* 17(3): 531-543.

Kraemer, J. E., and R. Bell. 1980. "Rain-induced mortality of eggs and hatchlings of loggerhead sea turtles (*Caretta caretta*) on the Georgian coast." *Herpetologica,* 36:72-77.

Kuroyanagi, K., and N. Kamezaki. 1993. "Growth of loggerhead hatchlings incubated at different temperatures." *Echolocation,* 14: 5-6.

Johannes, R. E., and D. W. Rimmer. 1984. “Some distinguishing characteristics of nesting beaches of the green turtle *Chelonia mydas* on North West Cape Peninsula, Western Australia.” *Marine Biology*, 83:149-154.

LeBlanc, A. M., and T. Wibbels. 2009. “Effect of daily water treatment on hatchling sea ratios in a turtle with temperature dependent sex determination.” *Journal of Experimental Zoology Part A: Ecological Genetics and Physiology,* 311(1):68-72.

LeBuff, C. R., Jr. 1974. “Unusual nesting relocation in the loggerhead turtle, *Caretta caretta*.” *Herpetologica,* 30:29-31.

Limpus, C. J., and R. L. Kamrowski. 2013. “Ocean-finding in marine turtles: the importance of low horizon elevation as an orientation cue.” *Behaviour, 150: 863-893*.

Limpus, C. J., V. Baker, and J. D. Miller. 1979. “Movement induced mortality of loggerhead eggs.” *Herpetologica,* 35(4):335-538.

Limpus, C. J., P. Reed, and J. D. Miller. 1983. “Islands and turtles. The influence of choice of nesting beach on sex ratio.” In *Proceedings: Inaugural Green Barrier Reef Conference*, pg. 397-402.

Lolavar, A., and J. Wyneken. 2015. “Effect of rainfall on loggerhead turtle nest temperatures, sand temperature and hatchling sex.” *Endangered Species Research,* 28(3):235-247.

Lorne, J. K., and M. Salmon. 2006. “Effects of exposure to artificial lighting on orientation of hatchling sea turtles on the beach and in the ocean.” *Endangered Species Research,* 3:23-30.

Lott, C. A., C. S. Ewell Jr, and K. L. Volansky. 2009. *Habitat associations of shoreline dependent birds in barrier island ecosystems during fall migration in Lee County, Florida*. ERDC/EL TR-09-14. Vicksburg, MS: US Army Engineer Research and Development Center.

Lucas, L. L. 2000. Results and assessment of a physical monitoring program associated with beach nourishment on high-density marine turtle nesting beaches in the center of the Archie Carr National Wildlife Refuge, Sebastian, Florida, USA. MS thesis, Florida Institute of Technology.

Lucas, L. L., B. E. Witherington, A. E. Mosier, and C. M. Koeppel. 2004. “Mapping marine turtle nesting behavior and beach features to assess the response of turtles to coastal armoring.” In *Proceedings of the 21st annual Symposium on Sea Turtle Biology and Conservation. National Oceanographic and Atmospheric Administration*, pg. 32-34. Technical Memorandum NMFS-SEFSC-528.

Lutcavage, M. E., P. Plotkin, B. Witherington, and P. L. Lutz. 1997. “Human impacts on sea turtle survival.” In *The Biology of Sea Turtles*, pg. 387-409. Boca Raton, FL: CRC Press.

Magron, J.-P. R. 2000. Impact assessment of beach nourishment on the physical environment of a high-density marine turtle nesting beach, Sebastian Inlet, Florida. MS Thesis. Florida Institute of Technology.

Mann, T. M. 1977. Impact of developed coastline on nesting and hatchling sea turtles in southeastern Florida. MS Thesis, Florida Atlantic University.

Marcovaldi, M. A., and A. Laurent. 1996. "A six season study of marine turtle nesting at Praia do Forte, Bahia, Brazil, with implications for conservation and management." *Chelonian Conservation Biology,* 2:55-59.

Martin, R. E. 1992. *Turtle nest relocation on Jupiter Island, Florida: An evaluation.* Presentation to the Fifth Annual National Conference on Beach Preservation Technology, February 12-14, 1992. St. Petersburg, Florida.

Maurer, A. S., and M. W. Johnson. 2017. "Loggerhead nesting in the northern Gulf of Mexico: Importance of beach slope to nest site selection in the Mississippi Barrier Islands." *Chelonian Conservation and Biology*, 16(2): 250-254.

Mazaris, A. D., A. S. Kallimanis, J. Tzanopoulos, S. P. Sgardelis, and J. D. Pantis. 2009. "Sea surface temperature variations in core foraging ground drive nesting trends and phenology of loggerhead turtles in the Mediterranean Sea." *Journal of Experimental Marine Biology and Ecology,* 379: 23-27.

Mazaris, A. D., Y. G. Matsinos, and D. Margaritoulis. 2006. "Nest site selection of loggerhead sea turtles: The case of the island of Zakynthos, W. Greece." *Journal of Experimental Marine Biology and Ecology,* 336: 157-162.

McGehee, M. A. 1990. "Effects of moisture on eggs and hatchlings of loggerhead sea turtles (*Caretta caretta*)." *Herpetologica,* 46(3):251-258.

Mellanby, R. J., A. C. Broderick, and B. J. Godley. 1998. "Nest site selection in Mediterranean marine turtles at Chelones Bay, Northern Cyprus." In *Proceedings of the 16th annual symposium on sea turtle biology and conservation*, 103–104. NOAA Technical Memorandum NMFS-SEFSC-412.

Meylan, A. B., B. Schroeder, and A. Mosier. 1995. *Sea turtle nesting activity in the State of Florida 1979-1992*. Florida Marine Research Publications Number 52, St. Petersburg, Florida.

Michel, J., A. C. Bejarano, C. H. Peterson, and C. Voss. 2013. *Review of biological and biophysical impacts from dredging and handling of offshore sand*. Herndon, VA: US Department of the Interior, Bureau of Ocean Energy Management.

Mihnovets, A. N. 2003. *Sea turtle monitoring project report Bogue Banks, North Carolina: Provisional Report*. North Carolina Wildlife Resource Commission.

Mihnovets, A. N., and M. H. Godfrey. 2004. *Sea turtle monitoring project report Bogue Banks, North Carolina: Interim report*. North Carolina Wildlife Resource Commission.

Miller, K., G. C. Packard, and M. J. Packard. 1987. "Hydric conditions during incubation influence locomotor performance of hatchling snapping turtles." *Journal of Experimental Biology,* 127:401-412.

Miller, J. D., C. J. Limpus, and M. H. Godfrey. 2003. "Nest site selection, oviposition, eggs, development, hatching, and emergence of loggerhead turtles." In *Loggerhead Sea Turtles*, 125-143. Washington, D.C.: Smithsonian Books.

Milton, S. L., A. A. Shulman, and P. L. Lutz. 1997. "The effect of beach renourishment with aragonite versus silicate sand on beach temperature and loggerhead sea turtle nesting success." *Journal of Coastal Research,* 13:904-915.

Moody, K. 1998. "The effects of nest relocation on hatchling success and emergence success of the loggerhead turtle (*Caretta caretta*) in Florida." In *Proceedings of the Sixteenth Annual Symposium on Sea Turtle Biology and Conservation*, 107-108. NOAA Technical Memorandum NMFS-SEFSC-412.

Mortimer, J. A. 1982. "Factors influencing beach selection by nesting sea turtles." In *Biology and Conservation of Sea Turtles*, 45-51. Smithsonian Institution Press, Washington, D.C.

Mortimer, J. A. 1990. "The influence of beach sand characteristics on the nesting behavior and clutch survival of green turtles (*Chelonia mydas*)." *Copeia,*802-817.

Mosier, A. E. 1998. The Impact of Coastal Armoring Structures on Sea Turtle Nesting Behavior at Three Beaches on the East Coast of Florida. MS Thesis, University of South Florida.

Mosier, A. E., and B. E. Witherington. 2002. "Documented effects of coastal armoring structures on sea turtle nesting behavior." In *Proceeding of the 20th annual Symposium on Sea Turtle Biology and Conservation*, 304-306. National Oceanographic and Atmospheric Administration Technical Memorandum NMFS-SEFC-477.

Mota, M. J. 2009. Beach restoration in Florida: Effects on sea turtle nesting and hatchling physiology. Ph.D. Dissertation, University of Florida.

Moulis, R. A. 1997. "Predation by the imported fire any (*Solenopsis invicta*) on loggerhead sea turtle (*Caretta caretta*) nests on Wassaw National Wildlife Refuge, Georgia." *Chelonian Conservation Biology*, 2:433-436.

Mrosovsky, N. 1983. "Ecology and nest-site selection of leatherback turtles, *Dermochelys coriacea*." *Biological Conservation,* 26:47-56.

Mrosovsky, N. 1994. "Sex ratios of sea turtle." *J. of Experimental Zoology,* 270:16-27.

Mrosovsky, N. 2006. "Distorting gene pools by conservation: assessing the case of doomed turtle eggs." *Environmental Management,* 38:523-531.

Mrosovsky, N. 2008. "Against oversimplifying the issues on relocating turtle eggs." *Environmental Management,* 41:465-467.

Mrosovsky, N., and M. H. Godfrey. 2010. "Editorial: Thoughts on climate change and sex ratios of sea turtles." *Marine Turtle Newsletter*, 128: 7-111.

Mrosovsky, N., and S. F. Kingsmill. 2010. "How Turtle Find the Sea." *Ethology,* 67(1-4):237-256.

Mrosovsky, N., and C. Pieau. 1991. "Transitional range of temperature, pivotal temperatures and thermosensitive stages for sex determination in reptiles." *Amphibia-Reptillia*, 12: 169-179.

Mrosovsky, N., and J. Provancha. 1992. "Sex ratio of hatchling loggerhead sea turtles: Data and estimates from a 5-year study." *Canadian Journal of Zoology*, 70, 530-538.

Mrosovsky, N., A. M. Granda, and T. Hay. 1979. "Seaward orientation of hatchling turtles; turning systems in the optic tectum." *Brain Behavior and Evolution*, 16:203-221.

National Research Council. 1995. "Environmental issues associated with beach nourishment." In *Beach nourishment and protection*, 107-126. Washington, D.C.: National Academy Press.

Nelson, D. A., and B. Blihovde. 1998. "Use of long wavelength lights to prevent disorientation of hatchling sea turtles." In *Proceedings of the 8th Annual Workshop on Sea Turtle Conservation and Biology*, 19-21. NOAA Technical Memorandum NMFS-SEFC-214.

Nelson, D. A., and D. D. Dickerson 1987. "Correlation of loggerhead turtle nest digging times with beach sand consistency." In *Seventh Annual Workshop on Sea Turtle Biology and Conservation*, 25-27 February 1987. Wekiwa Springs State Park, Florida.

Nelson, D. A., and D. D. Dickerson 1988. "Effects of beach nourishment on sea turtles." In *Proceedings of the first national Beach Preservation Technology Conference: Problems and Advancements in Beach Nourishment*, 285-294. Florida Shore and Beach Preservation Association, Tallahassee, Florida.

Nelson, D. A., and D. D. Dickerson 1989. "Effects of beach nourishment on sea turtles." In *Proceedings of the ninth annual workshop on Sea Turtle Conservation of Biology*, 125-127 National Oceanographic and Atmospheric Administration Technical Memorandum NMFS-SEFC-232.

Nelson, D. A., and K. Mauck. 1986. St. Lucie inlet dredged material disposal effects on the firmness of sand used by nesting turtles. Technical Report U.S. Army Corps of Engineers Waterways Experiment Station. Vicksburg, Mississippi. 28pp.

Nelson, D. A., K. Mauck, and J. Fletemeyer. 1987. *Physical effects of beach nourishment on sea turtle nesting, Delray Beach, Florida*. Technical Report EL-87-15. Vicksburg, MS: Waterways Experiment Station.

Nelson, W. G. 1985. *Physical and biological guidelines for beach restoration projects. Part I. Biological guidelines*. Report no.76. Gainesville, FL: Florida Sea Grant College.

NOAA. 2019. National Oceanic Atmospheric Administration, National Hurricane Center Database. https://www.nhc.noaa.gov/data/. Page last visited: 25 October 2019.

Ozan, C. R L. 2011. Evaluating the effects of beach nourishment on loggerhead sea turtle (*Caretta caretta*) nesting in Pinellas County, Florida. 60 p. https://digital commons.usf.edu/etd/3204

Özdemir, B., and O. Türkozan. 2006. "Hatchling success of original and hatchery nests of the green turtle, *Chelonia mydas*, in Northern Cyprus." *Turkish Journal of Zoology,* 30 (4): 377-381.

Packard, G. C., and M. J. Packard 1988. "The physiological ecology of reptilian eggs and embryos." In *Biology of the Reptilia*, Vol. 16, Ecology B. Defense and Life History, Alan R. Liss Inc., New York.

Packard, G. C., M. J. Packard, and M. D. Ashen. 1981. "Possible adaptive value of water exchange in flexible-shelled eggs of turtles." *Science,* 213:471-473.

Packard, G. C., M. J. Packard, and T. J. Boardmer. 1984. "Influence of hydration of the environment on the pattern of nitrogen excretion by embryonic snapping turtles (*Chelydra serpentine*)." *Journal of Experiment Biology,* 108:195-204.

Packard, G. C., M. J. Packard, and W. H. N. Gutzke. 1985. "Influence of hydration of the environment on eggs and embryos of the terrestrial turtle." *Terrayene ornate, Physiological Zoology,* 58(5):566-575.

Paramenter, C. J. 1980. "Incubation of the eggs of the green sea turtle, *Chelonia mydas*, in Torres Strait, Australia: The effect of movement on hatchability." *Australian Wildlife Research*, 7: 487-491.

Parkinson, R., J. White, and M. Perez-Bedmar. 1994. "Effects of beach nourishment on compaction, grain-size, moisture, and temperature: Sebastian Inlet, Florida." In *Proceedings of the 14th annual Symposium on Sea Turtle Biology and Conservation*, 112-114. National Oceanographic and Atmospheric Administration Technical Memorandum NMFSSEFC-351.

Patino-Martinez, J. A. M., L. Quiñones, and L. A. Hawkes. 2014. "The potential future influence of sea level rise on Leatherback turtle nests." *Journal of Experimental Marine Biology and Ecology*, 461: 116-123.

Pfaller, J. B., C. J. Limpus, and K. A. Bjorndal. 2008. "Nest-site selection in individual loggerhead turtles and consequences for doomed-egg relocation." *Conservation Biology,* 23 (1):72-80.

Pike, D. A. 2008a. "The benefits of nest relocation extend far beyond recruitment: a rejoinder to Mrosovsky." *Environmental Management*, 41:461-464.

Pike, D. A. 2008b. "Environmental correlates of nesting in Loggerhead turtles, *Caretta caretta*." *Animal Behaviour*, 76: 603-610.

Pike, D. A., and J. C. Stiner. 2007. "Sea turtle species vary in their susceptibility to tropical cyclones." *Oecologia,* 153: 471-478.

Pike, D. A., E. Roznik, and I. Bell. 2015. "Nest inundation from sea-level rise threatens sea turtle population viability." *Royal Society Open Science*, 2: 150127. http://dx.doi.org/10.1098/rsos.150127.

Pilkey, O. H. 1999. "Summary of Beach Nourishment Episodes on the U. S. East Coast Barrier Islands." *Journal of Coastal Research*, 15(4): 1100-1118.

Pilkey, O. H., and K. Dixon. 1996. *The Corps and the Shore*. Washington, D.C.: Island Press.

Pilkey, O. H., Jr., D. C. Sharma, H. R. Wanless, L. J. Doyle, Sr., O. H., Pilkey, W. J. Neal, and B. L. Gruver. 1984. *Living with the East Florida Shore*. Durham, NC: Duke University Press, 274p.

Pintus, K. J., B. J. Godley, A. McGowan, and A. C. Broderick. 2009. "Impact of clutch relocation on green turtle offspring." *Journal of Wildlife Management,* 73: 1151-1157.

Plant, N. G., and G. B. Griggs. 1992. "Interactions between nearshore processes and beach morphology near a seawall." *Journal of Coastal Research*, 8(1): 183-200.

Prange, H. D., and R. A. Ackerman. 1974. "Oxygen consumption and mechanisms of gas exchange of green turtle (*Chelonia mydas*) eggs and hatchlings." *Copeia*, 758-763.

Pritchard, P. C. H. 2004. "Long-term sea turtle nesting cycles in the Guianas." In *Proceedings of the 21st Annual Symposium on Sea Turtle Biology and Conservation*, 66-68. NOAA Technical Memorandum NMFS-SEFSC-528.

Provancha, J. A., and L. M. Ehrhart. 1987. "Sea turtle nesting trends at John F. Kennedy Space Center and Cape Canaveral Air Force Station, Florida, and relationships with factors influencing nest site selection." In *Ecology of East Florida Sea Turtles: Proceedings of the Cape Canaveral, Florida Sea Turtle Workshop*, 33-44. National Oceanographic and Atmospheric Administration Technical Report NMFS-53.

Rafferty, A. R., and R. D. Reina. 2014. "The influence of temperature on embryonic developmental arrest in marine and freshwater turtles." *Journal of Experimental Marine Biology and Ecology*, 450: 91-97.

Raymond, P. W. 1984. Effects of beach restoration on marine turtles nesting in south Brevard County, Florida. MS Thesis, University of Central Florida.

Reece, S. E., A. C. Broderick, B. J. Godley, and S. A. West. 2002. "The effects of incubation environment, sex and pedigree on the hatchling phenotype in a natural population of loggerhead turtles." *Evolutionary Ecology Research, 4:737-748.*

Rees, A. F., E. Tzovani, and D. Margaritoulis. 2002. "Conservation activities for protection of the loggerhead sea turtle (*Caretta caretta*) in Kyparissia." *Testudo,* 5:45-54.

Rimkus, T. A. 1992. The hydric and physical properties of natural and renourished beaches along the Atlantic Coast of Florida. MS Thesis, Iowa State University.

Rizkalla, C. E., and A. Savage. 2011. "Impact of Seawalls on Loggerhead Sea Turtle (*Caretta caretta*) Nesting and Hatching Success." *Journal of Coastal Research*, 27(1):166-173.

Roe, J. H., P. R. Clune, and F. V. Paladino. 2013. "Characteristics of a Leatherback Nesting Beach and Implications for Coastal Development." *Chelonian Conservation and Biology*, 12(1): 34-43

Rumbold, D. G., P. W. Davis, and C. Perretta 2001. "Estimating the effect of beach nourishment on *Caretta caretta* (Loggerhead Sea Turtle) nesting." *Restoration Ecology,* 9:304-310.

Ryder, C. E. 1993. The effect of beach renourishment on sea turtle nesting and hatching success at Sebastian Inlet State Recreation area East-Central, Florida. MS Thesis, Virginia Polytechnic Institute and State University.

Saba, V. S., C. A. Stock, J. R. Spotila, F. V. Paladino, and P. S. Tomillo. 2012. "Projected response of an endangered marine turtle population to climate change." *Nature Climate Change*, 2: 814-820.

Salmon, M. 2003. "Artificial night lighting and sea turtles." *Biologist,* 50: 163-168.

Salmon, M. 2006. "Protecting sea turtles from artificial lighting at Florida's oceanic beaches." In *Ecological consequences of artificial night lighting,* 141-168. Island Press, Washington, DC.

Salmon, M, R. Reiner, C. Lavin, and J. Wyneken. 1995a. "Behavior of loggerhead sea turtles on an urban beach. Part 1, Correlates of nest placement." *Journal of Herpetology*, 29: 560-567.

Salmon, M., M. G. Tolbert, D. P. Painter, M. Golf, and R. Reiners. 1995b. "Behavior of loggerhead sea turtles on an urban beach. Part II, hatchling orientation." *Journal of Herpetology*, 29: 568-576.

Salmon, M., J. Wyneken, E. Fritz, and M. Lucas. 1992. "Seafinding by hatchling sea turtles role of brightness, silhouette and beach slope as orientation cues." *Behaviour*, 122: 56-77.

Schmid, J. L., D. A. Addison, M. A. Donnelly, A. A. Shirley, and T. Wibbels. 2008. "The effect of Australian Pine (*Casuarina equisetifolia*) removal on loggerhead sea turtle (*Caretta caretta*) incubation temperatures on Keewaydin Island, Florida." *Journal of Coastal Research*, 55: 214-220.

Schroeder, B. A. 1994. "Florida index nesting beach surveys: are we on the right track?" In *Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation*, 132-133. NOAA Technical Memorandum NMFS-SEFSC-351

Schroeder, B. A., and A. E. Mosier. 1998. "Between a rock and a hard place: coastal armoring and marine turtle nesting habitat in Florida." In *Proceedings of the 18th International Sea Turtle Symposium* (Mazatlan, Mexico), 290-292.

Schulman, A. A., S. A. Milton, and P. L. Lutz. 1994. "Aragonite sand as a nesting substrate and its effect on *Caretta caretta* nests." In *Proceedings of the 14th annual Symposium for Sea Turtle Biology and Conservation*, 134. National Oceanographic and Atmospheric Administration Technical Memorandum NMFS-SEFSC-351.

Schwartz, F. J. 1982. "Correlation of nest sand asymmetry and percent loggerhead sea turtle egg hatch in North Carolina determined by geological sorting analyses." *Association of Southeastern Biologists Bulletin,* 29:83.

Shaw, K. R. 2013. Effects of Inundation on hatch Success of Loggerhead Sea Turtle (*Caretta caretta*) Nests. MS Thesis, University of Miami.

Silva, E., A. Marco, J. da Graca, H. Pérez, E. Abella, J. Patino-Martinez, S. Martins, and C. Almeida. 2017. "Light pollution affects nesting behavior of loggerhead turtles and predation risk of nests and hatchlings." *Journal of Photochemical Photobiology,* 173:240-249.

Sim, E. L., D. T. Booth, and C. J. Limpus. 2015. "Incubation temperature, morphology and performance in loggerhead (*Caretta caretta*) turtle hatchlings from Mon Repos, Queensland, Australia." *Biology Open*, 4(6): 685–692.

Spotila, J. R. 2004. *Sea turtles: A complete guide to their biology, behavior, and conservation*. Baltimore, Maryland: John Hopkins University Press.

Spotilia, J. R., G. A. Standora, S. J. Morreale, and G. J. Ruiz. 1987. "Temperature dependent sex determination the green turtle *Chelonia mydas*: Effects on the sex ratio on a natural beach.: *Herpetologica,* 43(1): pp.74-81.

Spotilia, J. R., G. A. Standora, S. J. Morreale, G. J. Ruiz, and C. Puccia. 1983. *Methodology for the study of temperature related phenomena affecting sea turtle eggs*. US Fish and Wildlife Service Endangered Species Report 11.

Standora, E. A., and J. R. Spotila. 1985. "Temperature-dependent sea determination in sea turtles." *Copeia,* 3:711-722.

Steinitz, M. J., M. Salmon, and J. Wyneken 1998. "Beach renourishment and loggerhead turtle reproduction: a seven-year study at Jupiter Island, Florida." *Journal of Coastal Research,* 14:1000-1013.

Stoneburner, D. L., and J. I. Richardson 1981. "Observations on the role of temperature in loggerhead turtle nest site selection." *Copeia,* 1981:238-241.

Thums, M., S. D. Whiting, J. Reisser, K. L. Pendoley, C. B. Pattiaratchi, M. Proietti, Y. Hetzel, R. Fisher, and M. G. Meekan. 2016. "Artificial light on water attracts turtle hatchlings during their near shore transit." *Royal Society Open Science*, 3:160142. http://dx.doi.org/10.1098/rsos.160142.

Trembanis, A. C., O. H. Pilkey, and H. R. Valverde. 1999. "Comparison of Beach Nourishment along the U. S. Atlantic, Great Lakes, Gulf of Mexico, and New England Shorelines." *Coastal Management,* 27:329-340.

Trindell, R. 2005. *Sea turtles and beach nourishment*. Florida Fish and Wildlife Conservation Commission, Imperiled Species Management Section. Invited Instructor, CLE Conference.

Trindell, R., M. Conti, D. Gallagher, and B. Witherington. 2008. "Sea turtles and lights on Florida's nesting beaches." In *Proceedings of the Twenty-fifth Annual Symposium on Sea Turtle Biology and Conservation*, 152-153. NOAA Technical Memorandum NMFS-SEFSC-582.

Trindell, R., D. Arnold, K. Moody, and B. Morford 1998. "Post-construction marine turtle nesting monitoring results on nourished beaches." In *Proceedings of the 1998 Annual National Conference on Beach Preservation Technology*, 77-92. Tallahassee, FL: Florida Shore & Beach Preservation Association.

Tucker, J. K., N. I. Filoramo, G. L. Paukstis, and F. J. Janzen. 1998. "Response of red-eared slider, *Trachemys scripta elegans*, to slightly differing water potentials." *Journal of Herpetology,* 32:124-128.

Turkozan, O., K. Yamamoto, and C. Yilmaz. 2011. "Nest site selection and hatchling success of green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) sea turtles at Akyatan Beach, Turkey." *Chelonian Conservation and Biology*, 10(2): 270-275.

Tuttle, J., and D. Rostal. 2010. "Effects of nest relocation on nest temperature and embryonic development of loggerhead sea turtles." (*Caretta caretta*). *Chelonian Conservation and Biology,* 9: 1.7.

Tuxbury, S. M., and M. Salmon. 2005. "Competitive interactions between artificial lighting and natural cues during seafinding by hatchling marine turtles." *Biological Conservation,* 121(2):311-316.

USACE. 2009. *Appendices to the Integrated General Reevaluation Report and Supplemental Environmental Impact Statement*. Brevard County, Florida: Hurricane and Storm Damage Reduction Project—Mid Reach Section.

USACE. 2010. *Statewide Programmatic Biological Assessment*. Beach Placement and Shore Protection, Coast of Florida. US Army Corps of Engineers, Jacksonville District.

USACE. 2011. *Final Integrated General Reevaluation Report and Supplemental Environmental Impact State, Brevard County, Florida*. Hurricane and Storm Damage Reduction Project, Mid Reach Segment, Revised 2011.

USACE. 2011. *Shore Protection Activities along the Coast of Florida*. Statewide Programmatic Biological Opinion. Prepared by the US Fish and Wildlife Service.

USACE 2013. Walton County, Florida Hurricane and Storm Damage Reduction, General Investigation Study, Draft FONSI and Environmental Assessment. https://www.sam.usace.army.mil

USFWS. 2015a. *Shore Protection Activities along the Coast of Florida*. Statewide Programmatic Biological Opinion (Revised).

USFWS. 2015b. Mississippi Coastal Improvement Program. *The Comprehensive Barrier Island Restoration Project Mississippi Sound Hancock, Harrison and Jackson Counties, Mississippi and Mobile County, Alabama*. Biological Opinion. Jackson, MS: US Fish and Wildlife Service.

USFWS. 2017. *North Carolina Coastal Beach Sand Placement*. Statewide Programmatic Biological Opinion. Service Log Number 04EN2000-2017-F-0126. 300pp.

Valverde, R. A., S. Wingard, F. Gómez, M. T. Tordoir, C. M. Orrego. 2010. "Field lethal incubation temperature of Olive Ridley sea turtle *Lepidochelys olivacea* embryos at a mass nesting rookery." *Endangered Species Research*, 12: 77-86.

Verheijen, F. 1985. "Photopollution: Artificial light optic spatial control systems fail to cope with incidents, causation, and remedies." *Experimental Biology*, 44: 1-18.

Ware, M., and M. M. P. B. Fuentes. 2018. "Potential for relocation to alter the incubation environment and productivity of sea turtle nests in the northern Gulf of Mexico." *Chelonian Conservation and Biology*, 17(2): 252-262.

Weishampel, Z. A., W. Cheng, and J. F. Weishampel. 2016. "Sea turtle nesting patterns in Florida vis-á-vis satellite-derived measures of artificial lighting." *Remote Sensing in Ecology and Conservation*, 59-72.

Wetterer, J. K., L. D. Wood, C. Johnson, H. Krahe, and S. Fitchett. 2007. "Predaceous ants, beach replenishment, and nest placement by sea turtles." *Entomological Society of America*, 36(5):1084-1091.

Whitmore, C. P., and P. H. Dutton. 1985. "Infertility embryonic mortality and nest site selection in the leatherback and green turtle in Suriname." *Biological Conservation,* 34:251-272.

Witherington, B. E. 1989. "Beach lighting and the seaward orientation of hatchling sea turtles." In *Proceedings of the Ninth Annual Workshop on Sea Turtle Conservation and Biology*, 189-190. NOAA Technical Memorandum NMFS-SEFC-232.

Witherington, B. E. 1990. "Photopollution on sea turtle nesting beaches: problems and next-best solutions." In *Proceedings of the Tenth Annual Workshop on Sea Turtle Conservation and Biology*, 43-45. NOAA Technical Memorandum NMFS-SEFC-278.

Witherington, B. E., K. A. Bjorndal, and C. M. McCabe. 1990. "Temporal pattern of nocturnal emergence of loggerhead turtle hatchlings from natural nests." *Copeia,* (4): 1165-1168.

Witherington, B. E. 1991. "Orientation of hatchling loggerhead turtles at sea off artificially lighted and dark beaches." *Journal of Experimental Biology and Ecology,* 149: 1-11.

Witherington, B. E. 1992a. “Behavioral responses of nesting sea turtles to artificial lighting.” *Herpetologica,* 48:31-39.

Witherington, B. E. 1992b. Sea finding behavior and the use of photic orientation cues by hatchling sea turtles. PhD. Dissertation, University of Florida.

Witherington, B. E. 1992c. “How are hatchling sea turtles able, and unable, to locate the sea?” In *Proceedings of the Eleventh Annual Workshop on Sea Turtle Conservation and Biology*, 127-130. NOAA Technical Memorandum NMFS-SEFC-302.

Witherington, B. E., and K. A. Bjorndal. 1991a. “Influences of wavelength and intensity on hatchling sea turtle phototaxis: implications for sea finding behavior.” *Copeia,* 1060-1069.

Witherington, B. E., and K. A. Bjornadal. 1991b. “Influences of artificial lighting on the seaward orientation of hatchling loggerhead turtles (*Caretta caretta*).” *Biological Conservation,* 55:139-149.

Witherington, B. S., Hirama, and A. Mosier. 2005. “The behavior of loggerhead sea turtles encountering barrier on their nesting beach: a measure of effects from coastal armoring.” In *Proceedings of the 25th International Sea Turtle Symposium* (Savannah, Georgia).

Witherington, B., S. Hirama, and A. Mosier. 2011. “Sea turtle response to barriers on their nesting beach.” *Journal of Experimental Marine Biology and Ecology,* 401(1-2): 1-6. DOI: 10.1016/j.jembe.2011.03.012.

Witherington B. E., and R. E. Martin. 1996. *Understanding, assessing, and resolving light-pollution problems on sea turtle nesting beaches*. Technical Report TR-2. Florida Marine Research Institute Technical Report.

Witherington, B. E., and R. E. Martin. 2003. *Understanding, assessing, and resolving light pollution problems on sea turtle nesting beaches*. Technical Report TR-2, Third edition. Revised Florida Marine Research Institute Technical Report.

Witherington, B., P. Kubilis, B. Brost, and A. Meylan. 2009. “Decreasing annual nest counts in globally important loggerhead turtle populations.” *Ecological Applicat*ions, 19:30–54.

Witherington, B. E., R. E. Martin, and R. N. Trindell. 2014. *Understanding, assessing, and resolving light pollution problems on sea turtle nesting beaches, revised.* Technical Report TR-2, vii. Florida Fish and Wildlife Research Institute.

Wood, D. W. 1998. Relation of temperature, moisture, conductivity, and beach slope to nest site selection in loggerhead sea turtles. MS Thesis, University of Florida.

Wood, D. W., and K. A. Bjorndal 2000. “Relation of temperature, moisture, salinity, and slope to nest site selection in loggerhead sea turtles.” *Copeia,* 1:119-128.

Wyneken, J., T. J. Burke, M. Salmon, and D. K. Pederson. 1988a. “Egg failure in natural and relocated sea turtle nests.” *Journal of Herpetology,* 22:88-96.

Wyneken, J., L. DeCarlo, L. Gleen, M. Salmon, D. Davidson, S. Weege, and L. Fisher. 1998b. "On the consequences of timing, location and fish for hatchlings leaving open beach hatcheries." In *Proceeding of the Sixteenth Annual Symposium on Sea Turtle Biology and Conservation*, 155-156. NOAA Technical Memorandum NMFS_SEFSC-412.

Wyneken, J., and A. Lolavar. 2015. "Loggerhead sea turtle environmental sex determination: implication of moisture and temperature for climate change based predictions for species survival." *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution*, 324(3):295-314.

Zavaleta-Lizárranga, L., and J. E. Morales-Mávil. 2013. "Nest site selection by the green turtle (*Chelonia mydas*) in a beach of the north of Veracruz, *Mexico*." *Revista Mexicana de Biodiversidad,* 84: 927-937.

Acronyms and Abbreviations

Term	Definition
BOEM	Bureau Of Ocean Energy Management
DMSP	Defense Meteorological Satellite Program
ESA	Endangered Species Act
FDEP	Florida Department of Environmental Protection
FWC	Florida Fish and Wildlife Commission
HDPE	High Density Polyethylene
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
USACE	U.S. Army Corps of Engineers
ERDC-EL	U.S. Army Engineer Research and Development Center – Environmental Laboratory
USFWS	U.S. Fish and Wildlife Service

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14. ABSTRACT

This Technical Report was developed by the U. S. Army Engineer Research and Development Center-Environmental Laboratory (ERDC-EL), to summarize the known impacts to nesting sea turtles along the Atlantic and Gulf Coasts resulting from beach nourishment. The U.S. Army Corps of Engineers (USACE) is responsible for maintaining the nation's infrastructure to include ports and harbors through dredging of Federal navigation channels as well as shoreline stabilization. Shoreline stabilization through beach nourishment activities can provide opportunities for reductions in storm surge, flood control, and provide opportunities for residential growth, recreational activities, and coastal habitat restoration (Guilfoyle *et al*. 2019). Beach nourishment is an effective method for protection and enhancement of coastal development projects but may have detrimental impacts on marine life (e.g., nesting sea turtles and shorebirds). The objective of this Technical Report is to examine all elements of the beach nourishment process to include, active beach construction, entrainment of marine turtles in hopper dredges, beach protection and hard structures, beach profile features, compaction and shear resistance, artificial lighting, marine turtle nest relocation, and nesting habitat factors. Recommendations for mitigating and minimizing these impacts are provided.

15. SUBJECT TERMS

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