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Evaluating the Effects of Beach Nourishment on Loggerhead Sea Turtle (Caretta caretta) Nesting In Pinellas County, Florida

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Evaluating the Effects of Beach Nourishment on Loggerhead Sea Turtle (*Caretta caretta*) Nesting In Pinellas County, Florida

By

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A thesis submitted in partial fulfillment
of the requirements for the degree of
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The health of Florida's beaches are vital to the survival of loggerhead sea turtles (*Caretta caretta*), as nearly half of the world's loggerheads nest on the states beaches. Many of the beaches utilized by the turtles have undergone nourishment projects in hopes of combating erosion of the shoreline, protecting beachfront property, and creating more suitable beaches for tourism. Although it is argued that beach nourishment benefits sea turtles by providing more nesting habitat, the effects of the Pinellas County nourishment projects on loggerhead nesting are unknown. Beach nourishment can alter the compaction, moisture content, and temperature of the sand, all of which are variables that can affect nest site selection and the proper development of eggs. This research has four objectives: (1) to create a GIS dataset using historic loggerhead sea turtle data collected at the individual nest level along the West coast of Florida, (2) to examine the densities of loggerhead nests, the densities of false crawls (i.e. unsuccessful nesting attempts), and the nest-to-false crawl ratio on natural and nourished beaches for the 2006-2010 nesting seasons; (3) to determine the effects of beach nourishment projects on the hatchling success rates and emergence success rates; and (4) to determine areas preferred or avoided by turtles for nesting.

The study found that nesting and false crawl densities significantly differed between natural and nourished beaches during three of the five nesting seasons. Nesting densities increased directly following nourishment and false crawl densities were higher in nourishment areas during every nesting season. False crawl densities were higher than statistically expected on nourished beaches and lower than expected on natural beaches. No significant differences were found between hatchling and emergence success rates between natural and nourished beaches. However, when the rates were analyzed by nesting season, the average hatching and emergence success rates were always lower on nourished beaches than on natural beaches. A hotspot analysis on nests and false crawls revealed that turtles preferred natural beaches that border nourished areas for nesting while false crawls were more evenly distributed through the study area.

Although this study documents the negative effects of beach nourishment on loggerhead sea turtle nesting, nourishment projects are likely to continue because of their benefits to human populations. Further examining of the impacts that humans have on nesting and developing loggerheads will ultimately aid policy formation as we continue to manage and protect the future of the species.

CHAPTER 1:

INTRODUCTION

Every year Florida's beaches host an estimated 45% of the world's nesting loggerhead sea turtle (*Caretta caretta*) population (Meylan 1982). This reproductive concentration provides researchers with a unique opportunity to study the species. Studies within the oceanic and neritic habitats largely focus on documenting the life history of loggerheads, as well as quantifying the effects that commercial fisheries and marine pollution have on populations. However, population estimates are hard to determine using data collected from the oceanic and neritic zones, since individuals are widely dispersed throughout the water and are difficult to locate. Accordingly, researchers commonly use nesting data collected in the terrestrial habitat to estimate overall population sizes and trends. Using methods based on nesting data, researchers estimate that Florida's loggerhead sea turtle populations have declined by 29% to 51% over the past 20 years (Witherington et al. 2009).

Although trawling fisheries are thought to be responsible for the majority of losses within the population (Crouse *et al*. 1987), researchers are now examining possible effects of human induced beach alterations on nesting. Human development within the loggerhead’s terrestrial habitat can alter the geomorphology of the beaches as well as increase light pollution. Physical changes to areas of the beach where turtles emerge from the water, sand composition, and habitat stability may alter nesting patterns and influence nest success.

This research aims to enhance the existing body of literature on Florida loggerhead populations by addressing the impacts of coastal management, specifically beach nourishment, on nesting patterns. Coastal managers often use beach nourishment to mitigate erosion and protect coastlines from storms while providing a more pleasurable beach environment for people, which can benefit the local economy through increased tourism. Beach nourishment is also purported to create a variety of environmental benefits, which include the creation of wildlife habitat, via beach widening, for nesting sea birds and sea turtles (Pinellas County 2009). The effects of beach nourishment on loggerhead sea turtle nesting have been examined on Florida’s East coast, where nesting density is high (Weishampel 2003). Research there suggests that successful nesting on nourished beaches declines in the few years following the project due to changes in the sand compaction, escarpment, and beach profile (Rumbold 2001, Steinitz et al. 1998, Trindell et al. 1998). However, this does not address the effects on egg development or the ability of hatchlings to emerge from the nest.

This research identifies trends in nesting densities and success rates of Florida’s unique Gulf coast loggerhead turtles on both natural and nourished beaches. The individual objectives of this research include: (1) to create a GIS dataset using historic loggerhead sea turtle data collected at the individual nest level along the West coast of Florida, extending from North Clearwater Beach to Pass-a-Grill Beach (2) to examine the densities of loggerhead nests, the densities of false crawls, and the nest-to-false crawl ratio on both natural and nourished beaches for each of the nesting seasons; (3) to determine the impacts of beach nourishment projects on hatching and emergence success rates for loggerhead nests; and (4) to determine areas of the coastline preferred or avoided by loggerheads for nesting.

This thesis is organized as follows. Chapter 2 provides a literature review of loggerhead sea turtle ecology, reproduction, population ecology, population trends, threats to populations, and management and protection. Chapter 3 describes the study area. Chapter 4 outlines the methodology of the study, while Chapter 5 presents the results of the research. Chapter 6 provides a discussion of the findings and offers recommendations for policies and future research. Finally, Chapter 7 summarizes the main conclusions of the research.

CHAPTER 2:

LITERATURE REVIEW

Loggerhead Sea Turtle Ecology

Loggerhead sea turtles are one of seven living species of marine turtles. Unlike other reptile species, loggerheads are widely distributed, residing throughout tropical and temperate regions of the Pacific, Atlantic, and Indian oceans (Bowen et al. 1993, NOAA 2009). According to the National Marine Fisheries Service (Recovery Plan 2008), the following are the three basic ecosystems in which loggerheads can live:

1. The oceanic zone—the open ocean environment, from the surface of the water to the sea floor, where depths exceed 200 meters.
2. The neritic zone—areas of the ocean where water depths are less than 200 meters, including the continental shelf.
3. The terrestrial zone—the nesting beach where egg laying, embryonic development and hatching occurs.

Tagging data has been proven to be effective in determining the mobility and range of loggerheads within these three ecosystems. Research suggests that adult turtles migrate every two to three years from coastal foraging grounds in the neritic zone to reproductive areas, traveling anywhere from two to thousands of kilometers (Limpus et al. 1992, Meylan 1982). During non-nesting years adult females from U.S. beaches are distributed in waters off the eastern U.S., the Bahamas, Greater Antilles, Yucatán, and throughout the Gulf of Mexico (Recovery Plan 2008). Tagging data from Sarasota, FL, has shown that some turtles remain in the vicinity after nesting, while others migrated to the southwestern Florida shelf, the northeast Gulf of Mexico, the south Gulf of Mexico, or the Bahamas (Girard, Tucker, and Calmettes 2009). Both males and females return to the same feeding grounds after reproductive migration, although the females are unique in that they return to the same nesting beaches (Limpus et al. 1992).

Conversely, post-hatchlings do not partake in migration. After entering the water, they reside in the neritic zone from weeks to months before being carried away by ocean currents (Witherington 2002). Juvenile loggerheads have been found to passively drift along oceanic currents for 7 to 11.5 years before recruiting to neritic coastal feeding grounds as sub-adults, where they will reside until sexual maturity is reached (Carr 1986). It is hypothesized that sub-adults reside in the coastal feeding grounds due to a physical barrier created by strong Gulf currents. Until a sufficient mass is reached, they are not able to contest the currents leading into the oceanic zone (Girard, Tucker, and Calmettes 2009). Reproductive migrations occur after sub-adults spend 13 to 20 years in the neritic zone feeding and growing to a size that is optimal for reproduction (Bjorndal et al. 2000).

Reproduction

Loggerhead sea turtles are long-lived reptiles often exceeding 57 years of age, taking up to 35 years to reach sexual maturity (Dahlen et al. 2000). Loggerheads are iteroparous, with a reproductive output that is distributed between periodic nesting ventures with each migration to nesting beaches. Individuals will make the migration every few years. Within any period of reproductive migration, females lay several clutches of eggs. Although the mean number of clutches per season is believed to be four (Murphy and Hopkins 1984, Witherington et al. 2009), up to eight nests have been recorded for a single loggerhead in one nesting season (Tucker 2009). It is important for researchers to properly estimate clutch frequency as it is used to estimate population sizes. Gravid females come onshore at night or early morning, ideally above the high tide line, to deposit their eggs. They typically nest on open sand, but they may also nest in the sea oat dunes behind the beach (Carr 1986). The gravid female digs an egg chamber before depositing up to 130 golf ball-sized eggs. She carefully fills in the chamber with moist, packed sand, and attempt to cover her tracks before returning to the water.

Depending on the temperature, loggerhead eggs require 55 to 60 days of incubation (NOAA 2009, Witherington et al. 2009). Incubation temperatures control sex determination during embryogenesis. Heat shock proteins, identified as heterogeneous nuclear ribonucleoprotein particles (hnRNPs), are responsible for temperature-dependant gene expression (Harry et al. 1990). Males are determined at 26 °C and females at a warmer 32 °C (Harry et al. 1990). Fluctuating incubation temperatures produce a mixture of both sexes, with the pivotal temperature that produces an equal mixture of both sexes being 29°C (Limpus et al. 1985, Harry et al. 1990, Recovery Plan 2008). It can take 1 to 3 days for loggerhead hatchlings to pip and escape from their eggs and 2 to 4 days for the hatchlings to emerge from the nesting chamber. (Christens 1990). The hatchlings use the decreasing sand temperature as a cue to emerge and lighting from the moon as a cue to find the ocean (Mrosovsky 1968).

Population Ecology

Population structures of loggerhead sea turtles have been extensively studied. Early studies involved tag and recapture and direct observation methods. Tag and recapture studies have indicated that females return to the same nesting beach each reproductive migration, however it is not clear if this is a product of natal homing, which means that females return to the same beaches they were hatched on (Limpus et al. 1992). Direct observation methods have provided information regarding social interactions and a variety of behaviors, however, results from such studies cannot be extrapolated to the population due to the difficulty of sampling a large enough portion of the population (Schofield *et al*. 2006)

The evolution of genetic assays has provided a more accurate and efficient means to study population structures compared to the traditional methods. Genetic-based studies using microsatellite deoxyribonucleic acid (DNA) and maternally inherited mitochondrial (mt) DNA suggest that loggerhead sea turtles have complex population structures, varying between sexes and life stages (Bowen et al. 2005 and Bowen et al. 1993). Assays of the Atlantic and Mediterranean populations using mtDNA depict a significant genetic differentiation between the two locations. This suggests that female mediated gene flow between rookeries is uncommon, supporting the theory of nest site fidelity.

Within the Atlantic, nesting loggerheads are divided into Florida, South Carolina, and Georgia cohorts (Bowen et al. 1993). The Florida population is further divided; beaches separated by 100 km have been shown to host distinct populations (NOAA 2009). Few significant differences between populations were found when microsatellite DNA was analyzed, suggesting that male turtles provide gene flow between regional nesting colonies through migration, while distinct differences found between mtDNA provides evidence for the natal homing theory (Bowen et al. 2005).

Population Trends

The broad geographic distribution of loggerhead sea turtles in the water makes studying the species a difficult task. Therefore, methods for estimating populations have primarily relied on data collected from nesting beaches (Meylan 1982, Murphy and Hopkins 1984, Witherington et al. 2009). Researchers have analyzed nesting data from around the world and have identified only two nesting areas that support more than 10,000 females per year: Masirah, Oman, and Florida, USA. Nesting beaches in these two areas host 80-90% of the world's loggerhead sea turtle nests (Ehrhart et al. 2003; Tucker 2009, Witherington et al. 2009).

In Florida, the Florida Fish and Wildlife Conservation Commission (FWC) is responsible for coordinating surveys of nesting beaches. Permit holders consisting of local government and federal agencies, conservation groups, consultants, and volunteers survey the beaches in effort to collect nesting data. The Statewide Nesting Beach Survey (SNBS) and Index Nesting Beach Survey (INBS) programs have been implemented simultaneously in hopes that they would complement one another (FWC 2008). The two programs have slight differences in their goals. The SNBS program strives to have complete seasonal and geographic coverage; however, data collection has not been consistent due to fluctuations of boundaries. The INBS program has aimed to be consistent, nevertheless it has not been complete in seasonal and geographic coverage (Witherington et al. 2009). The data collected under the two programs provide researchers with a means to reliably estimate the number of nesting females in a given area and identify trends within the population over time (FWC 2008).

Researchers have primarily used nesting data gathered from the INBS in an attempt to assure quality control of the nesting data (Witherington et al. 2009). A study by Witherington et al. (2009) analyzed loggerhead nest counts on Florida's index beaches from 1989 to 2006. Within all Florida's subregions, nesting increased by 25-27% from 1989 to 1998 but then declined by 43-44% from 1998 to 2006. The percent change in the population was 29% to 51%, with the steepest decline in population occurring in the Southwest subregion

(Witherington et al 2009). Loggerhead sea turtles are faithful to their nesting beaches, making it highly unlikely that the females are being recruited to other cohorts. It is generally accepted that a decline in nest counts is caused by a decline in the local population. However, there has been documentation of large shifts in spatial nesting distribution for three species of sea turtles in South America following geomorphologic changes to the nesting beaches (Pritchard 2004). This suggests that the degree of site fidelity may be flexible when nesting conditions are not satisfactory.

Researchers have also attempted to determine population sizes and trends in the marine environment; however this has proven to be difficult and costly. Short-term trends have been established within a limited number of neritic sites. Nevertheless, extrapolating the localized trends to the broader population is a problem of scale and requires data from several foraging grounds (Bjorndal *et al*. 2005, Recovery Plan 2008). Trends are analyzed using data collected from aerial surveys, sightings, and counts from trawl nets and power plant intake structures. The results of these studies do not conclusively indicate a change in the population (Morreale et al. 2005, Mansfield 2006, Ehrhart et al. 2007).

Threats to the Population

There are several threats to loggerhead sea turtles within the oceanic and neritic environments, which include: incidental catch in commercial fisheries, disease, vessel strikes, cold water, ingestion of marine debris, and illegal harvesting; all of which may be partially responsible for the decline in Florida’s population. Incidental catches in commercial fisheries is one of the most detrimental threats to oceanic and neritic loggerhead sea turtles. Shrimp trawling has proven to be the greatest obstacle to the recovery of the population (Recovery Plan 2008). Before protective legislation was in place, scientists estimated that annual loggerhead bycatch fatalities from shrimping fleets in the southeast U.S. Atlantic and the Gulf of Mexico numbered between 5,000 and 50,000 (National Research Council 1990). When turtles are captured in the nets, they cannot reach the surface for air, causing death by drowning. Unfortunately, most of the fatalities were juveniles at the size and age that has the greatest impact on reproductive output (Crowder et al. 1994, Lutz, Musick, Wyneken 2003). The threat of trawling gear has decreased in recent years with advancements in Turtle Exclusion Devices (TEDs), which will be further discussed in *Management and Protection*.

Longline fisheries in both the neritic and oceanic zones also have negative impacts on loggerheads (Long and Schroeder 2004, Laurent et al. 1998, Watson et al. 2005). The primary longline fishery devastating the loggerhead population is the bottom longline shark fishery (Recovery Plan 2008). Longline shark gear was responsible for 785 loggerhead mortalities from 2004 to 2006 in the Gulf of Mexico (Richards 2007). In the oceanic environment, research had shown that swordfish longline fisheries are mostly affecting juvenile turtles, the most abundant class of loggerheads in the oceanic stage (Bolten et al. 1994, Chaloupka 2003).

The overharvesting of fisheries has also threatened loggerhead populations by changing trophic interactions within the neritic and oceanic environments.. Changes to trophic interactions may decrease food resources for loggerheads, which could have a devastating effect on growth rates and reproduction. Diet shifts in loggerheads brought on by overfishing have been documented; however, few studies have focused on the long-term effects of dietary changes (Recovery Plan 2008, Seney and Musick 2007).

Changes in predator-prey relationships due to overfishing are considered to be a threat to the population; changes in the food webs could cause loggerheads to become prey to new predators (Bjorndal 2003). In the oceanic stage, small sharks and other large carnivorous fish and mammals within the ecosystem prey upon loggerheads, while large sharks prey upon neritic loggerheads. Tiger sharks and bull sharks are the species most reported to contain loggerhead sea turtle remains. (Simpfendorfer *et al*. 2001, Fergusson *et al*. 2000). However, the magnitude of loggerhead mortality caused by predation is unknown (Recovery Plan 2008).

Marine debris entanglement and ingestion is also a major threat to oceanic and neritic loggerheads (Bugoni 2001, Carr 1986, and Witherington 2002). Pollution in the open ocean and near shore environments is abundant. It has been found that loggerheads frequently ingest monofilament fishing line, hooks, tar, styrofoam, and plastics due to low feeding discrimination (Tomas 2002). Effects of ingestion include obstruction of the gut, absorption of toxic byproducts, and reduced absorption of nutrients across the gut wall, all of which can be fatal (Balazs 1985). Juvenile turtles are particularly affected by debris ingestion. Convergences bring floating substrates, such as sea grass rafts, and the turtles together. Unfortunately, plastic, tar balls and other pollutants are brought to the floating substrates. The turtles can ingest the debris and potentially incur mortality from the effects (Recovery Plan 2008). Witherington and Hirama (2006) found that 33.7% of stranded post-hatchlings had ingested tar and 83.1% had ingested plastic. This problem is not unique to Atlantic loggerheads. Tomas (2002) found that of 54 loggerheads illegally captured in Spanish Mediterranean waters, 79.6 % had ingested plastic and tar.

Threats faced by loggerhead sea turtles in the terrestrial zone are distinctive from threats faced in the open water; however they are equally perilous to the population. Individual threats include the presence of humans, light pollution, sand placement, beach armoring, shoreline stabilization, and shoreline construction (Recovery Plan 2008). Human activity on the beach can negatively affect the loggerhead population. The use of recreational equipment, such as beach chairs, umbrellas, and cabanas, can deter nesting or obstruct hatchlings during their migration to sea. Research suggests that unsuccessful nesting attempts, termed false crawls, and destruction of eggs are correlated with recreational equipment left on the beach at night (Sobel 2002). Humans performing species management activities, such as nesting surveys and tagging, also have the potential to adversely affect nesting females, developing eggs, and hatchlings by causing disturbance. However, most activities have minimal effects and the benefits attributed to management activities usually outweigh the risks (Recovery Plan 2008).

Beach nourishment projects also pose a threat to loggerhead sea turtles in the terrestrial environment. Beach nourishment is the placement of sand on highly eroded beaches to mitigate erosion, protect against storms, and create a larger beach area. Florida's coastline is exposed to strong erosion due to storms and oceanic currents. Before humans developed beach environments, the effects of erosion on sea turtle nests were minimal since removed sand could be replaced with sand from behind the beach or adjacent areas. The placement of buildings, jetties, inlets, roads, and cities along the coast has altered this natural process (Steinitz et al. 1998).

There are many factors that influence nesting behaviors and the success of a nest, including the moisture of the sand, temperature range, sediment characteristics, compaction of the sediment, and various types of human activity (Davis et al. 1999). Successful turtle nesting requires a narrow temperature range and a dry beach with loosely compacted sediment to facilitate excavation by the nesting female (Nelson 1998). However, the sediment on many of Florida's Gulf beaches has changed due to beach nourishment. Nourished beaches are wider and flatter, and the sediment tends to be more compact and moister than the sediment on natural beaches (Ernest and Martin 1999). Beach nourishment provides more nesting habitat for the turtles. However, nesting usually declines in the nourished areas for the first few years following nourishment (Rumbold 2001, Steinitz et al. 1998, Trindell et al. 1998). The reduction in nesting females on nourished beaches have been attributed to an increase in sand compaction, which puts an energy burden on the female and can increase nest construction time, causing females to return to the water without depositing their eggs (Rumbold 2001, Trindell et al. 1998). Beach nourishment can also affect the incubation environment by altering the moisture content, gas exchange, and temperature of the sediment (McGehee 1990). However, studies examining the effects of nourishment on the development of embryos are not lacking (Recovery Plan 2008).

Beach armoring and shoreline stabilization can also adversely affect loggerhead nesting. While armoring with sea walls creates a barrier between the water and the nesting habitat, shoreline-stabilizing structures (jetties and inlets) can have effects on adjacent beaches due to alterations in long shore sediment transport (Recovery Plan 2008). Research has shown that inlets and jetties on the Atlantic coast of Florida are negatively correlated with nesting density, possibly due instability of the shoreline in the immediate areas (Witherington et al. 2005).

An increase in development along nesting beaches is also associated with light pollution, which can adversely affect nesting and hatchling loggerheads (Witherington 1992). Nesting females rely on visual cues to find their way back to the water; those nesting on brightly lighted areas may become disoriented or misdirected. Hatchlings also rely on visual cues to find their way to the water. They have a tendency to orientate towards the brightest direction over the horizon, which can be away from the ocean on highly developed beaches. Hatchlings that are not able to find the water, or are delayed from reaching it, often die from dehydration, exhaustion, or predation. Estimates from six counties in Florida suggest that hundreds of thousands of hatchlings are adversely affected by light pollution each year (Ehrhart and Witherington 1987). Light pollution is considered to be dangerous to sea turtles if any portion of the light can be seen from an observer anywhere on the beach. Research suggests that hatchlings can even become disoriented from indirect light in the form of glowing skies around highly developed coastal areas (Witherington et al. 1994).

Management and Protection

Due to the decline in population, several national and international laws have been created to protect loggerhead sea turtles. On July 28, 1978, the loggerhead sea turtle was listed under the Endangered Species Act (ESA) as a threatened species throughout its range. They are also listed in Appendix I of the Convention on International Trade of Endangered Species (CITES), in Appendix I and II of the Convention on Migratory Species (CMS), and under Annex II of the Specially Protected Areas and Wildlife (SPAW) Protocol of the Cartagena Convention. The United States is also a member of the Inner-American Convention for the Protection and Conservation of Sea Turtles (IAC) (NOAA 2009).

The development of protective measures in trawling fisheries has been a significant objective in loggerhead management. In 1978 the NMFS initiated the development of TEDs, which is a device that allows captured turtles to escape from shrimp nets. The original design was a cage-like apparatus that proved to be dangerous to fisherman. Modern TEDs consist of a metal grid or ramp that directs turtles to an opening in the net. The NMFS now requires that TED designs be 97% effective in excluding sea turtles (NOAA 2009). Although TEDs have been effective at reducing mortalities associated with trawling, they are not required in all trawling fisheries and program funding limits the enforcement of regulations (Recovery Plan 2008). The highly migratory behavior of loggerheads can hinder conservation efforts, as the degree of protection can vary among nations. Conservation efforts in one country can be jeopardized by lack of management practices or enforcement in others. Protecting loggerheads in U.S. waters alone is not sufficient to ensure the continued existence of the species; a collaborative effort is necessary (Fleming 2001, Recovery Plan 2008).

CHAPTER 3:

STUDY AREA

This research utilizes loggerhead sea turtle nesting data collected on beaches in Pinellas County, Florida. Pinellas County is located on Florida's gulf coast and is the second smallest county in the state, with a land area of 250 square miles. The county is ranked sixth in population and is the most densely populated county within Florida, with 3,372 residents per square mile. The dense population and development make Pinellas County an ideal study area for effectively evaluating the effects of human development on loggerhead sea turtle nesting. The nesting data were collected on beaches located on a series of barrier islands that stretch from North Clearwater Beach (28°3'3.3258" N, 82°,49'2.442" W) to Pass-a-Grill Beach (27°40'55.2282" N, 82°44'15.6984" W) (Figure 1). Other popular beaches within this area include Sand Key Beach, Indian Rocks Beach, Treasure Island, and Saint Petersburg Beach.

The study area consists of a mix of natural beaches and beaches that have been nourished. In this context, natural beaches are characterized by the state of their sediment, having not been nourished within the last 10 years. Nourished beaches are defined as areas that transported sediment was placed during county supervised nourishment projects taking place within the last 10 years. Nourishment projects in Pinellas County are a common management solution to the problem of beach erosion and are generally well supported by local communities and government officials due to the many benefits that they are perceived to have. The widening of sand beaches protects against erosion by acting as a natural buffer between powerful gulf storms and the mainland while boosting tourism and the local economy. In addition, the wide beaches are also thought to benefit wildlife, such as sea birds and sea turtles, that depend on the sandy habitat for nesting (Pinellas County 2010). The natural areas of the barrier islands will serve as the control areas for this study while the 2004 nourishment project area (NPA), the 2005/2006 NPA, and the 2006 NPA will serve as test areas.

The 2004 NPA took place on 1.56 miles of beach just south of Blind Pass in southern Pinellas County (Figure 2). The area, identified as Upham Beach, has a history of nourishment. However, the 1996 nourishment of Upham Beach resulted in 83 % of the fill eroding within 22 months (Elko and Mann 2007). The 2004 renourishment project placed 330,000 cubic yards of sand on the existing beach. T-head groins were strategically placed along the beach to prevent erosion in the project area. In 2006 the beach was up to 100 ft. wider than it was in 2002; however, the success of the project is debatable (Elko and Mann 2007).

The 2005/2006 NPA consists of the nourished portion of Sand Key, a barrier island that stretches from Clearwater Pass to John’s Pass. The project placed 2 million cubic yards of sand along 6.8 miles of the beach, from the

Clearwater portion of Sand Key to North Redington beach, excluding Belleair Shores (Figure 3). The fill sand was dredged from Egmont Shoals, just offshore of the entrance to Tampa Bay. The 2005/2006 project was the fifth phase of a long-term project, which began in 1988. Five T-head groins were already in place to prevent erosion of the fill (Pinellas County 2009).

The 2006 NPA consists of three non-contiguous beach areas totaling 2 miles, including: (1) Sunshine Beach, (2) Sunset Beach, and (3) Upham Beach (Figure 4). The erosion history of long key is well documented in early aerial photographs. The unregulated costal developments in the 1950's, including the dredge and fill construction that was common on the back bays, created a 150 m loss of beach. Seawalls and groins were constructed through the 1960s and 1980s to mitigate erosion. The 2006 project places 270,000 cubic yards of sand dredged from Egmont shoals on the three areas. The three beaches are on a 4-year management plan and are continually monitored (Pinellas County 2009).

Figure 1. Beaches of Pinellas County Florida (Madera Beach Information 2011)

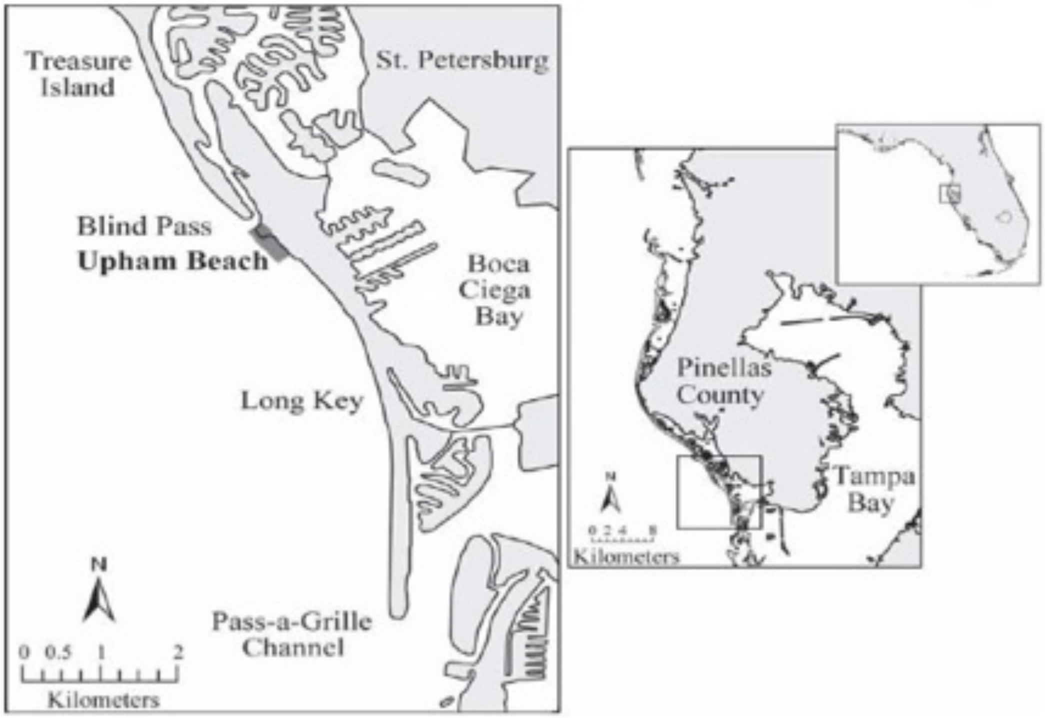

Figure 2. 2004 Nourishment Project Area at Upham Beach (Modified from Upham Beach 2010).

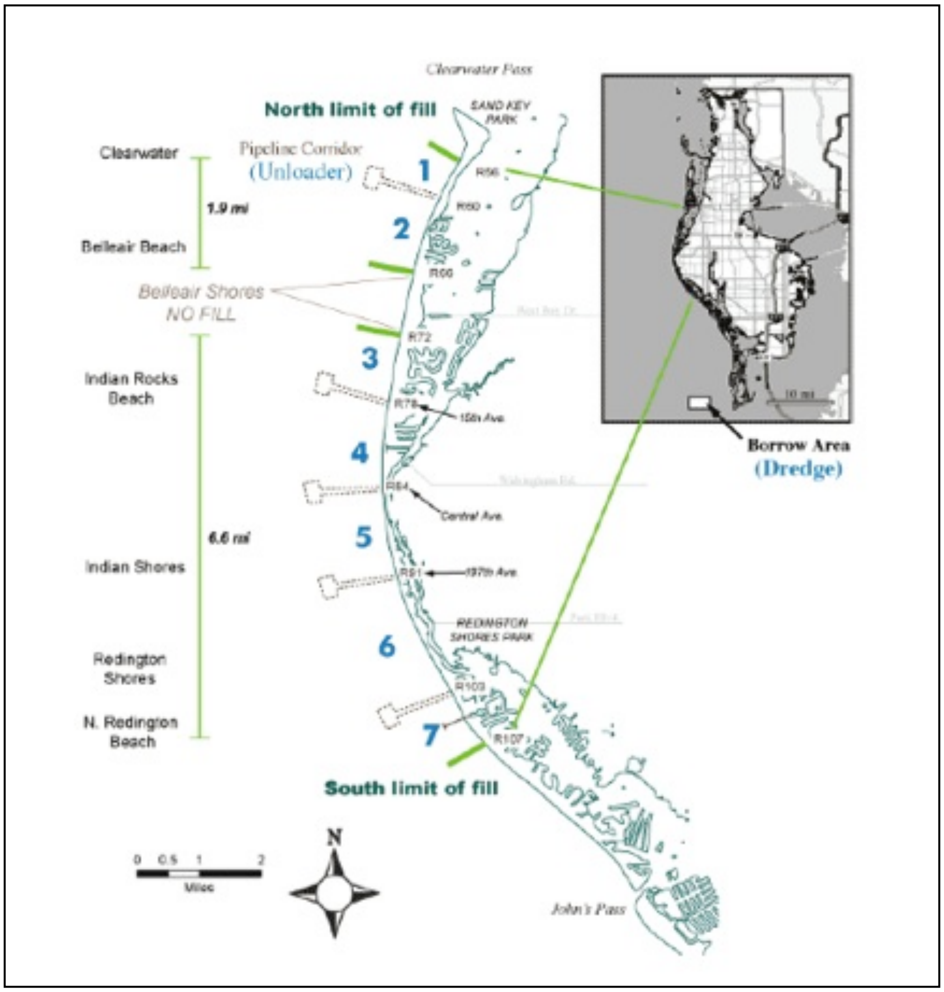

Figure 3. 2005/2006 Nourishment Project Area (Pinellas County 2009)

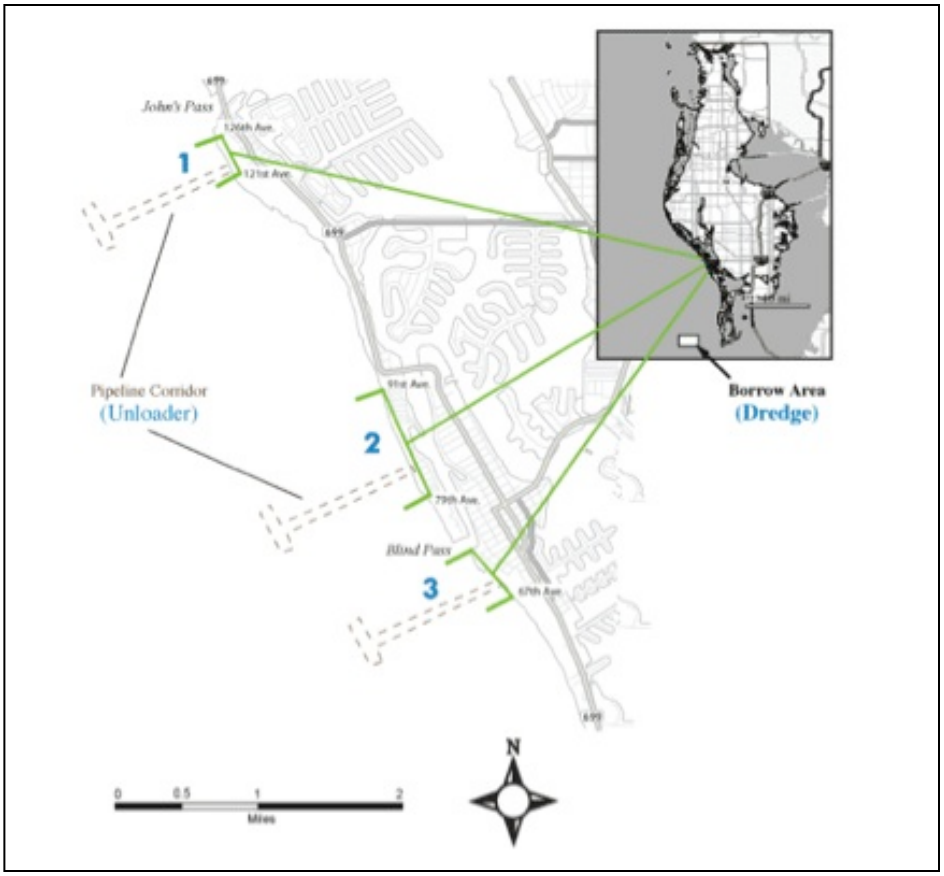

Figure 4. 2006 Nourishment Project Area (Pinellas County 2009)

CHAPTER 4:

METHODOLOGY

The National Marine Fisheries Service (NMFS) and the Florida Fish and Wildlife Conservation Commission (FWC) oversee the monitoring of sea turtle nesting along Florida's coastline. Individual permit holders are responsible for data collection in a given area and report annual nest counts and false crawls to the FWC. The FWC has developed strict protocol for data collection under two complimentary programs, the Statewide Nesting Beach Survey program (SNBS) and the Index Nesting Beach Survey (INBS) program. The SNBS program was initiated in 1979, which collaborates with the INSB program that was activated 14 years later. Of the 190 SNBS areas, 33 participate in the INBS program. Index and statewide nesting data have proven to be valuable in estimating local population sizes and trends, however they are overly general to be used for fine scale studies pertaining to nest site selection and hatchling success rates. Therefore, the first step in this research was to obtain data collected at the individual nest level within the study area and to use that information to create a GIS database. The created geodatabase was used to compute nest and false crawl densities, nest-to-false crawl ratios, and hatching and emergence success rates for all natural and nourished beaches within the study area. Additionally, a hotspot analysis was used to identify particular locations preferred or avoided by sea turtles for nesting.

Data Collection

The Clearwater Marine Aquarium (CMA) is a 501(c)(3) nonprofit organization that was selected by the FWC in 1987 to monitor 26 miles of beaches in Pinellas County for nesting activity. As permit holders, they are required to report total annual nest counts and total false crawls for each nesting season within their monitoring area. For their own records, the CMA also collects data on individual nests. Individual nesting data were collected from 1989 to the present; however, up until 2000 it was a common practice to relocate nests when deemed necessary and data recording and storage was not consistent. In order to ensure accuracy, only data collected from 2006-2010 were used in the analysis. The following data collection methods have been consistent over the time period of interest and follow guidelines provided by the FWC.

Trained staff members, interns, and volunteers surveyed the beaches seven days a week in the early morning hours throughout the nesting season (May-September) by foot and on all-terrain vehicles. Surveyors used visual cues to identify sea turtle tracks and nest mounds. Although the majority of sea turtle nests are from loggerheads, green sea turtles and leatherbacks occasionally nest in the area (FWC 2008). The surveyors are trained to identify which species of sea turtle came ashore by key characteristics of the crawl, which are tracks and other signs left by turtles. Loggerhead sea turtle crawls exhibit a unique pattern of alternating comma-shaped flipper marks with a smooth track center with no well-defined tail-drag mark. Crawling patterns from green and leatherback sea turtles have parallel flipper marks and a well-defined tail drag. After identifying the species, the surveyors determined if there was a nest or if it was a false crawl. A successful nest was identified when there was evidence of front flipper covering and a secondary body pit and escarpment were present. A false crawl, or an abandoned nesting attempt, was identified when there was little or no sand disturbed other than the tracks, when there was a backstop present over emerging crawl, when the crawl exits the disturbed area toward the dune before turning toward the ocean, or when an empty, smooth-walled or collapsing egg chamber was observed. When a crawl did not exhibit characteristics that clearly indicate a successful nest, surveyors cautiously dug using their hands to confirm the presence of eggs. The surveyors noted the location of each nest and false crawl using a hand-held GPS to ensure nests were only counted once. If a nest was confirmed, four wooden posts were placed in the sand to form one square meter that encompasses the nesting cavity. Wire cages were placed over the nest cavity to prevent predation on eggs and hatchlings and colorful tape was used to close off the area in between the posts to keep beach visitors off the nest. To minimize human disturbances, a sign was also posted that warns of the legal consequences of disturbing a nest.

Marked nests were monitored no less than every other day to ensure accurate nest fate information and to identify the hatch date. Staff members and interns also monitored the nests late night in hopes to observe hatchling emergence. Three days after hatchling emergence or on day seventy of incubation, whichever was shorter, the nest were excavated and inventoried. The numbers of hatched and un-hatched eggs are recorded on a productivity worksheet along with any other nest fate information (FWC 2008).

Geodatabase Creation

The nesting data collected during 2006-2010 by CMA was imported into a commercial geographic information system, ArcGIS v. 9.3 (ESRI), for storage, visualization, and analysis. First, a spatial data layer representing the locations of individual nests and false crawls as points was created from the recorded GPS coordinates. The nesting date, false crawl date, species, number of eggs laid, hatch date, number of eggs hatched, and nest fate information were recorded as attributes in the resulting database. Additional spatial data layers were also created that represented the spatial extents of the natural and nourished beaches within the study area using boundaries provided by Pinellas County Coastal Managers and the Clearwater Marine Aquarium. The geodatabase was then used to map the nest and false crawl locations, compute the areas of natural and nourished beaches, calculate nesting and false crawl densities, compute hatching and emergence success rates, and identify particular areas sea turtles preferred or avoided for nesting.

Methods

Nest and False Crawl Densities

The second step of this research was to use the created geodatabase to calculate nesting densities, false crawl densities, and nest-to-crawl ratios for natural and nourished beach areas. Nesting and false crawl densities were calculated for each nourishment project area and the natural beach area. The length of each area was determined using functions in the GIS software and the number of nests and false crawls in each area were counted. The nesting density (ND) was calculated as follows: $ND = n_{(x)}/l_{(x)}$; where *n* equals the number of nests in area x and l equals the length (mi) of area x. Similarly, the false crawl density (FCD) was calculated as follows: $FCD = fc_{(x)}/l_{(x)}$; where fc equals the number of false crawls in area x and l equals the length (mi) of area x. Nest-to-crawl ratios (NCR) were calculated for natural areas and each of the nourishment project areas using the following formula: $NCR = n_{(x)}:fc_{(x)}$; where n equals the number of nests in area x and fc equals the number of false crawls in area x.

The nest-to-crawl ratios were used for a chi-squared (X^2, DeVeaux, Vellemen and Bock 2009) test in order to determine if the number of nests and false crawls each nesting season was correlated with the beach status. The X^2 values were calculated using the expected and observed nests and false crawls for each nesting season. The number of expected nests and false crawls for each test area were calculated using the number of observed nests/false crawls for each season and the size of the beach area. Second, nesting densities, false crawl densities, and nest-to-crawl ratios were compared over time for both natural and nourished beaches. Additionally, changes in the frequency of nests and false crawls were compared for nourished beaches during each year post-nourishment as per Steinitz et al. (1998) to evaluate trends throughout the nesting seasons.

Hatching and Emergence Success Rates

The next phase of the research was to examine the effects of beach nourishment projects on hatching success (HS) and emergence success (ES) rates within the study area. To test the effects of the nourishment projects on hatchling success rates, the numbers of hatched and un-hatched eggs were used to calculate the percent of successful hatches for each nest in natural and nourished areas. The emergence success rates were also calculated, as not all hatched turtles fully emerge from the nest. The HS rate was calculated as follows: $HS = nP_{(x)}/nT_{(x)} \times 100\%$; where nP equals the number of pipped eggs in nest x and nT equals the total number of eggs in nest x. The ES rate was calculated as follows: $ES = (nP_{(x)} - nD_{(x)})/nT_{(x)} \times 100\%$; where nP equals the number of piped eggs in nest x, nD equals the number of deceased hatchlings excavated from nest x, and nT equals the total number of eggs in nest x. All nests identified as a washout, or eggs that suffered water damage from a tropical storm or hurricane, were removed from the dataset to avoid influence of the variable. The average HS and ES rates for nesting seasons 2006-2010 were calculated and examined for spatial and temporal trends on natural and nourished beaches. The percent increase or decrease in HS and ES rates were calculated to determine if nourished beaches impede turtles as they are piping the egg or crawling up and out of the nest.

A two-way analysis of variance (ANOVA, DeVeaux, Vellemen and Bock 2009) was run on the hatching and emergence data using the beach state and nesting year as fixed factors. ANOVA is a common statistical procedure used to test for differences in means among populations. ANOVA was used to determine if the HS and ES rates significantly differed on natural and nourished beaches. The individual ES and HS values for each nest from 2006 to 2010 were used in the analysis. A Tukey multiple comparisons of means test was performed at a 95% family-wise confidence level to determine if HS or ES significantly differed between nesting seasons. Again, the individual ES and HS rates for each nest were used in the analysis. Finally, the temporal trends of HS and ES rates were identified for both natural and nourished beaches.

Beach Preference and Avoidance

A hotspot analysis was conducted using kernel density estimation (KDE, Silverman 1986) in order to identify preferred and undesirable nesting habitat. In this context, successful nests were considered preferred locations, while false crawls were assumed as evidence of habitat avoidance. KDE is a popular statistical data smoothing technique that operates by fitting distance-weighting kernel functions to each data point in order to generate a continuous density surface. As such, KDE was applied separately for nest and false crawl locations in order to identify hotspots of each behavior. Optimal bandwidth selections were made using least squares-cross validation and hot spots were identified as areas containing 50% of the intensity. The 50% areas for both nesting and false crawls were intersected with the nourishment areas to determine sites preferred or avoided by nesting loggerheads.

CHAPTER 5:

RESULTS

Nest and False Crawl Densities

The 2006 nesting season resulted in 110 loggerhead sea turtle nests and 121 false crawls. Nesting density was highest within the 2006/2006 NPA, with 7.50 nests per mile. Substantially lower nesting densities of 2.54, 3.21, and 2.54 were found in the natural beaches, 2006 NPA and the 2004 NPA respectively. In 2006 false crawl densities were highest on the 2004 NPA, with 9.09 false crawls per mile. False crawl densities within the 2005/2006 NPA, natural areas, and 2006 NPA were 5.16, 3.43, and 0.77 respectively (Table 1).

Table 1. Nesting Densities and False Crawl Densities for Natural and Nourished Areas for the 2006 Nesting Season

Area	Nesting Density (n/mi)	False Crawl Density (fc/mi)
Natural	2.54	3.43
2004 NPA	3.21	9.09
2005/06 NPA	7.50	5.16
2006 NPA	4.25	0.77

The 2007 season yielded 38 nests and 49 false crawls, resulting in the lowest overall nesting and false crawl densities over the extent of the study. Nesting densities were highest in the 2006 NPA with 6.56 nests/mile, followed by the Natural Area with 1.47 nests/mile. There were no nests reported in the 2004 NPA and 2005/2006 NPA, resulting in a nesting density of 0. False crawl densities were 2.97 false crawls/mile in the 2004 NPA; followed by 1.47 false crawls/mile on the natural beaches (Table 2).

Table 2. Nesting Densities and False Crawl Densities for Natural and Nourished Areas for the 2007 Nesting Season

Area	Nesting Density (n/mi)	False Crawl Density (fc/mi)
Natural	1.47	1.47
2004 NPA	0.00	2.97
2005/06 NPA	0.00	0.00
2006 NPA	6.56	0.00

In 2008 there were 108 nests and 71 false crawls. Nesting densities were highest in the natural areas, with 4.26 nests/mile. The 2005/2006 NPA had 3.96 nests/mile, the 2005/2006 NPA had 2.7nests/mile, and the 2004 NPA contained 1.92 nests/mile. False crawl densities were highest in the nourished project areas. The 2006 NPA contained 3.47 false crawls/mile; followed by the 2005/06 NPA with 2.67, 2005/06 NPA with 2.67 false crawls/mile (Table 3).

Table 3. Nesting Densities and False Crawl Densities for Natural and Nourished Areas for the 2008 Nesting Season

Area	Nesting Density (n/mi)	False Crawl Density (fc/mi)
Natural	4.26	2.52
2004 NPA	1.92	1.28
2005/06 NPA	3.96	2.67
2006 NPA	2.70	3.47

The 2009 nesting season yielded 138 nests and 109 false crawls. The 2005/2006 NPA had a nesting density of 7.58 nests/mile, the natural beaches had a density of 4.05 nests/mile, the 2006 NPA had a density of 2.70 nests/mile, and the 2004 NPA area had a density of 2.56 nest/mile. The false crawl density on the natural area was 2.59 false crawls/mile. The false crawl densities were highest on nourished beaches. The 2005/2006 NPA had a density of 8.45 false crawls/mile, the 2004 Nourishment project area had 5.82 false crawls/mile, and the 2006 NPA contained 3.29 false crawls per mile; while the natural area had a density of 2.59 false crawls/mile (Table 4).

Table 4. Nesting Densities and False Crawl Densities for Natural and Nourished Areas for the 2009 Nesting Season

Area	Nesting Density (n/mi)	False Crawl Density (fc/mi)
Natural	4.05	2.59
2004 NPA	2.56	5.82
2005/06 NPA	7.58	8.45
2006 NPA	2.70	3.29

The 2010 nesting season resulted in 119 loggerhead sea turtle nests and 97 false crawls. Nesting density was highest within the 2005/06 NPA, with 5.17 nests per mile. Nesting densities of 4.25, 3.91, and 3.21 were found in the 2006 NPA, natural area, and the 2004 area respectively (Table 5). In 2006 false crawl densities were also highest within the 2005/2006 NPA, with 6.15 false crawls/mile. The natural beaches had a density of 2.38 false crawls/mile, the 2004 NPA had a density of 1.92 false crawls/mile and the 2006 NPA contained 1.54 false crawls/mile (Table 5).

Table 5. Nesting Densities and False Crawl Densities for Natural and Nourished Areas for the 2010 Nesting Season

Area	Nesting Density (n/mi)	False Crawl Density (fc/mi)
Natural	3.91	2.38
2004 NPA	3.21	1.92
2005/06 NPA	5.17	6.15
2006 NPA	4.25	1.54

Nest to False Crawl Ratio

The numbers of nests in natural areas were greater than or equal to the numbers of false crawls in natural areas for every season except 2006. In 2006, 2008, and 2010 there were false crawls than nests in the 2004 NPA. In 2007 there were more false crawls than nests in nourished areas and in 2010 there were an equal number of nests and false crawls in the nourished areas (Table 6). The nest to false crawl ratio in natural areas increased over time, while the nest to false crawl ratio in the NPAs fluctuated with between nesting seasons (Table 6).

Table 6. Nest to False Crawl Ratio (N:FC) for all Nesting Seasons in Natural and Nourished Areas

Beach Type	2006	2007	2008	2009	2010
Natural	43:58	21:21	61:36	58:38	56:33
2004 NPA	5:14	0:1	3:2	4:9	5:3
2005/06 NPA	75:47	0:27	36:24	69:59	47:56
2006 NPA	11:2	17:0	7:9	7:8	11:4

A chi-squared test was used to determine if the number of nests and false crawls during each nesting season was dependent on the beach status. The number of false crawls and nests in the 2006, 2009, and 2010 nesting seasons were found to be significantly dependent on the state of the beach. The distributions of false crawls and nests in the 2007 and 2008 nesting season were not significantly dependant on the beach state (Table 7).

Table 7. Chi-squared and *p*-values for the number of nests and false crawls on natural and nourished beaches from 2006 to 2010

Year	d.f.	X^2	*p*-value
2006	3	53.9	<0.001
2007	3	2.92	0.404
2008	3	0.63	0.891
2009	3	27.2	<0.001
2010	3	20.3	<0.001

Hatching and Emergence Success Rates

Hatching and emergence success rates were calculated for each nesting season on both natural and nourished beaches. Each nesting season, the average HS rate was higher than the average ES rate for both natural and nourished beaches. The average HS and ES rates were higher on natural beaches for all nesting seasons. The percent decrease in ES rates from natural to nourishes beaches were greater than the percent decrease in HS rates for all nesting seasons (Table 8 and 9). The average HS rate decreased from natural to nourished beaches by 2.15 % in 2006, 2.93% in 2007, 4.11% in 2008, 1.87% in 2009 and 3.67% in 2010 (Table 8). The average ES rate decreased from natural to nourished beaches by 2.72 % in 2006, 8.51% in 2007, 5.15% in 2008, 2.55% in 2009 and 4.39% in 2010 (Table 9).

Table 8. Differences in average hatching success rates between natural and nourished beaches from 2006-2010

Beach Type	2006	2007	2008	2009	2010
HSR Natural (%)	86.33	83.10	77.99	80.71	65.39
HSR Nourished (%)	84.18	17:28	47:35	76.19	63:63
% Difference	(2.15)	(2.93)	(4.11)	(1.87)	(3.67)

Table 9. Differences in average emergence success rates between natural and nourished beaches from 2006-2010

Beach Type	2006	2007	2008	2009	2010
ESR Natural (%)	84.32	80.73	75.88	74.53	63.94
ESR Nourished (%)	81.60	72.22	70.73	71.98	59.55
% Difference	(2.72)	(8.51)	(5.15)	(2.55)	(4.39)

The ANOVA compared the HS and ES rates at the individual nest level between both nourished and natural beaches by year. The ANOVA found no significant difference between the HS rates from natural beaches and the HS rates from nourished beaches (*p*=0.11) but it did show significant differences between nesting seasons (*p*<0.01) (Table 10). The overall trend was a decrease in HS and ES over time. Similarly, there were no significant differences between the ES rates from natural and nourished beaches (p= 0.2081), but they differed significantly between nesting seasons (p<0.01) (Table 11). The degrees of freedom, sum of squares, mean sum of squares, and *F* statistics from the analyses are included in Tables 10 and 11. The Tukey test indicated that individual HS and ES rates were significantly lower in 2009 and 2010 (*p*<0.01), while the HS and ES rates in 2006, 2007, and 2008 were similar to one another.

Table 10. ANOVA for hatchling success rates on natural and nourished Beaches

	d.f.	Sum Sq	Mean Sq	F-value	p-value
Beach State	1	1332	1332	2.56	0.110
Nesting Year	4	586959	586959	282.09	<.001
Residuals	461	239798	520		

Table 11. ANOVA for emergence success rates on natural and nourished Beaches

	d.f.	Sum Sq	Mean Sq	F-value	p-value
Beach State	1	862	862	1.59	0.208
Nesting Year	4	559016	129754	282.09	<.001
Residuals	461	250209	543		

Beach Preference and Avoidance

The KDE revealed clusters of nests and false crawls within the study area. Beaches with the highest concentrations of nests included: North Clearwater Beach, Bellaire Beach, Bellaire Shoals, South Redington Beach, Upham Beach, and Sunset Beach. Upham Beach falls within the 2004 NPA and Bellaire Beach falls within the 2005/06 NPA, while North Clearwater Beach, Bellaire Shoals, and South Redngton Beaches are natural beaches, most of which share a border with one of the NPAs (Figure 5). The false crawls were dispersed more uniform throughout the study area. The beaches with the highest concentrations of false crawls include: Bellaire Beach, Bellaire Shoals, Indian Rocks Beach, Indian Shores Beach, Madeira Beach, and Treasure Island. Bellaire Beach, Indian Rocks Beach, and Indian Shores Beach are within the 2005/2006 NPA while Treasure Island is within the 2006 NPA. Bellaire Shoals and Madeira beaches are natural beaches (Figure 6).

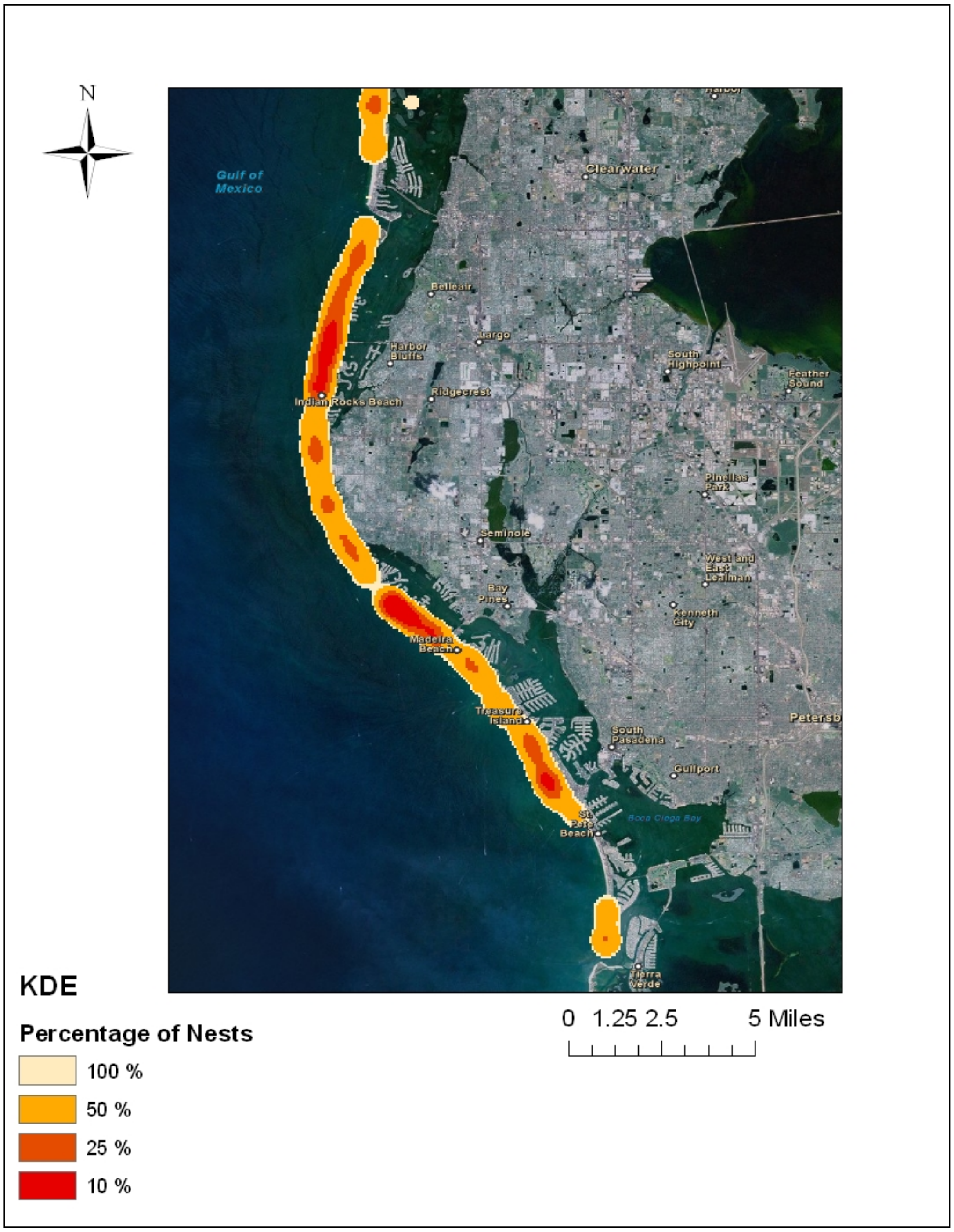

Figure 5: Kernel Density Estimation for all Nests From 2006-2010

Figure 6: Kernel Density Estimation for all False Crawls From 2006-2010

CHAPTER 6:

DISCUSSION

Nest and False Crawl Densities

When analyzing the nest to false crawl ratio by nesting season there were more nest than false crawls on both natural and nourished beaches. This was expected, as there were more nests (n=518) than false crawls (n=447) over the extent of the study. The chi-squared test was useful in determining if the incidence of nesting and false crawls were dependent on the beach status. This test accounted for the differences in size of natural and nourished areas. Although the test produced mixed results depending on the nesting year, it is interesting to note that the observed and expected false crawls exhibited a similar pattern every season. The false crawls on natural beaches were always less than expected, while the false crawls on nourished beaches were always more than expected. It is not likely that the higher instances of false crawls on nourished beached can be attributed to an attraction towards nourished beaches, since this pattern is not present with turtle nests. Nesting and false crawl densities were approached spatially and temporally. Nesting densities and false crawl densities in the natural areas were consistent over the nesting seasons, while the NPAs exhibited fluctuation in nesting densities and false crawl densities depending on the nesting season. False crawl densities were higher in the NPAs when compared to the false crawl densities in the natural areas for every nesting season. Previous research suggests that nesting behavior can be influenced by characteristics of the sediment, including compaction and moisture content (Davis et al. 1999). The female turtles are powerful diggers, but coming ashore to nest requires a large energy expenditure. The process of digging a nesting chamber in the nourished areas can be difficult or unsuitable due to such changes in the substrate (Crain et al. 1995, Rumbold 2001, Steinitz et al. 1998, Trindell et al. 1998). This could explain the higher than expected occurrences of false crawls on the nourished beaches. The high nesting densities directly following nourishment projects in 2006 and 2007 were observed in the 2005/2006 NPA and the 2006 NPA. The 2005/2006 NPA took place along 7.5 miles of beach, so the increased availability of nesting habitat directly following the projects may have lead to an increase of nesting in the new habitat, resulting in the inflated density. Temporal analysis would benefit from the addition of data collected during nesting seasons several years prior to the nourishment projects. However, the data collection methods and storage were not consistent before 2006.

Hatching and Emergence Success Rates

The hatchling and emergence success rates proved to be valuable in determining the effects of beach nourishment on loggerhead sea turtle nesting. The ANOVA results did not find a significant difference between individual HS and ES rates for all seasons on natural vs nourished beaches; however, the analysis did not account for natural fluctuations between nesting seasons, where HS and ES declined over time. When the HS and ES rates were examined by nesting season, a pattern was evident. For every nesting season, the average HS rates were 2.15% to 4.11% lower on nourished beaches than they were on natural beaches. Similarly, the average ES rates were lower by 2.72% to 8.15% on nourished beaches. The lower HS rates may be attributed to a change in the oxygen levels, moisture, or temperature within the nesting chamber, all of which are crucial to the proper development of loggerhead sea embryos (McGehee 1990). The differences in ES rates could be explained by the hatchlings inability to dig their way out of the nesting chamber due to compaction of the sand during the nourishment process. According to previous studies, the effects of nourishment on loggerhead nesting should decrease over time, but is often highest in the few years following nourishment. (Rumbold 2001, Steinitz et al. 1998, Trindell et al. 1998). This research shows that the HS and ES rates decreased over time. However, the trend cannot be interpreted as an effect of beach nourishment because the linear trend was similar for both natural and nourished beaches and the differences were statistically insignificant.

Beach Preference and Avoidance

The KDE revealed that the majority of the nesting hotspots were located on natural beaches or on nourished beaches that share a border with natural beaches. The increase in new nesting habitat could be responsible for the observed hotspots on border beaches. Border beaches may play an important role in successful nesting because it offers the benefits of both natural and nourished beaches in the form of wider beaches, like its nourished counterparts, and loosely compacted sand, like its natural counterparts. The false crawl hot spots were more dispersed throughout the study area, occurring on both natural and nourished beaches with a few hot spots within the NPAs.

Future Research and Recommendations

The U.S. Fish and Wildlife Services has placed conditions on 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 (Recovery Plan 2008). However, remediation techniques need to be reviewed for effectiveness. For example, Pinellas County is responsible for tilling nourished beaches following a nourishment project to reduce compaction. However, tilling has only been found to reduce compaction for one year (Nelson and Dickerson 1988). Policies requiring yearly tilling of nourished beaches prior to nesting season may help to minimize the effects of changes in the sediment. As such, future research dedicated to tracking changes in the sediment following nourishment projects would be useful in determining a future course for mitigating compaction and the subsequent changes in moisture, gas exchange, and temperature.

Although a monitoring program in currently in place, the frequency and diligence of monitoring can always be improved. Implementing policies that require monitoring of moisture content and temperature on nourished beaches during the nesting season is fiscally feasible. The FWC would not have to hire additional employees, as the contracted agencies are out every morning monitoring the nests. I highly recommend that the FWC require permit holders to note the temperature, oxygen, and moisture content of the substrate when a nest is confirmed.

Human impacts on loggerhead nesting habitats extend well beyond beach nourishment. Development along the shoreline increases light pollution, which has been shown to disturb nesting females and disorient hatchlings (Witherington 1992). The placement of armoring structures, such as jetties and T-groins, can block nesting females from coming on shore and have been shown to decrease nesting in the surrounding areas (Recovery Plan 2008, Witherington et al. 2005). The number of people accessing the beach could have an effect on nesting patterns, as beaches that are highly used would have more chairs, umbrellas, and beach toys; all of which have been documented to interrupt nesting (Sobel 2002). All of the aforementioned variables may play a role in the nesting patterns observed in this study. As such, future research should explore the relationship between light pollution, armoring structures, and beach usage on nesting patterns and nest success rates in Pinellas County.

Chapter 7:

Conclusion

Loggerhead sea turtles nest on natural and nourished beaches in Pinellas County, however nesting density was greater and HS and ES rates were higher on natural beaches. False crawls were more prevalent on NPAs and the HS and ES rates were lower in NPAs during each year. Nesting activity increased in nourished areas of the beach when more nesting habitat became available in the years directly following the 2005/2006 and 2006 nourishment projects. However, there is no guarantee that the addition of new habitat was suitable for nesting loggerheads. The challenges that come with nesting on nourished beaches, such as having to dig through highly compacted sand, may be responsible for the higher than expected instances of false crawls within the NPAs.

A vital issue that has been identified in this research is the decrease in HS and ES rates from natural to nourished beaches for each nesting season. The lower HS rates on nourished beaches are likely due to changes in the nesting substrate that can effect embryonic development, such as moisture and oxygen content. The lower ES rates on nourished beaches could be a result of an increase in the compaction of the sand, hindering the hatchlings ability to emerge from the nesting chamber.

Although this study documents some negative effects of beach nourishment on loggerhead sea turtle nesting, nourishment projects are likely to continue because of their benefits to human populations. Future research examining the changes in the sediment following nourishment, in conjunction with studies accounting for light pollution, beach armoring, and the degree of beach usage is recommended. Further examining of the impacts that humans have on nesting and developing loggerheads will ultimately aid policy formation as we continue to manage and protect the future of the species.

Works Cited

Balazs, G.H. Impact of ocean debris on marine turtles: entanglement and ingestion.Pages 387-429 i*n* Shomura, R.S. and H.O. Yoshida (editors). 1985. Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. NOAA Technical Memorandum NMFS/SWFC-54.

Bjorndal, K. A. "Ingestion of Marine Debris by Juvenile Sea Turtles in Coastal Florida Habitats." *Marine pollution bulletin* 28.3 (1994): 154.

Bjorndal, K.A., “Sea Turtle Nesting in Melbourn Beach Florida” *Biology Conservation* 26 (1983): 65.

Bjorndal, K.A. “Roles of loggerhead sea turtles in marine ecosystems”. The Biology of Sea Turtles V2 (2003): 2008

Bjorndal, K.A. and A.B. Bolten (editors). 2000. Proceedings of a workshop on assessing abundance and trends for in-water sea turtle populations. NOAA Technical Memorandum NMFS-SEFSC-445. 83 pages.

Bjorndal, K.A., A.B. Bolten, and H.R. Martins. “Somatic growth model of juvenile loggerhead sea turtles *Caretta caretta*: duration of pelagic stage”. *Marine Ecology Progress Series* 202 (2000): 250.

Bolten, A.B. and B.E. Witherington (editors). 2003. Loggerhead Sea Turtles. Smithsonian Books, Washington D.C. 319 pages.

Bolten, A.B., K.A. Bjorndal, and H.R. Martins. “Life history model for the loggerhead sea turtle (*Caretta caretta*) population in the Atlantic: potential impacts of a longline fishery” The Biology Of Sea Turtles V2 (2003): 243.

Bowen, B., et al. “Population Structures of Loggerhead Turtles (Caretta carreta) in the Northwest Atlantic Ocean and Med. Sea”. *Conservation Biology* 7.4 (1993): 834.

Bowen, B. W. "Conservation Implications of Complex Population Structure: Lessons from the Loggerhead Turtle (Caretta Caretta)." *Molecular ecology* 14.8 (2005): 2389.

Bugoni, L. "Marine Debris and Human Impacts on Sea Turtles in Southern Brazil." *Marine pollution bulletin* 42.12 (2001): 1330.

Carr, A. “Rips, FADs, and little loggerheads”. *Bioscience* 36 (1986) :92.

Chaloupka M (2003) Stochastic simulation modeling of loggerhead population dynamics given exposure to competing mortality risks in the western South Pacific. In: Bolten AB, Witherington BE (editors) Loggerhead sea turtle. Smithsonian Books, Washington DC, pp 274–294

Christens, E. “Nest emergence lag in loggerhead sea turtles”. *Journal of Herpetology* 24.4 (1990):400.

Crain, D.A., Bolten, A.B., Bjorndal, K.A., Effects of beach nourishment on sea turtles: review and research initiatives. *Restoration Ecology* 3 (1995):95.

Crowder, L. B. "Predicting the Impact of Turtle Excluder Devices on Loggerhead Sea Turtle Populations." *Ecological Applications* 4.3 (1994): 437.

Crouse, D.T., L.B. Crowder, and H. Caswell. A stage-based population model for loggerhead sea turtles and implications for conservation*. Ecology* 68 (1987): 1423.

Dahlen, M.K., R. Bell, J.I. Richardson, and T.H. Richardson. “Beyond D-0004: Thirty four years of loggerhead (*Caretta caretta*) research on Little Cumberland Island, Georgia,1964-1997”. NOAA Technical Memorandum. (2000): 293.

Davis, R.A., FitzGerald, M.V., Terry, J. Turtle nesting on adjacent nourished beaches with different construction style: Pinellas County, Florida. *Journal of Coastal Research* 15 (1999): 111.

DeVeaux, Velleman, and Bock. “Intro Stats” New York, Pearson (2009)

Ehrhart LM, Bagley DA, Redfoot WE (2003) Loggerhead turtles in the Atlantic Ocean: geographic distribution, abundance,and population status. In: Loggerhead Sea Turtles (eds Bolten AB, Witherington BE), pp. 157–174. Smithsonian Institution,Washington, DC.

Ehrhart, L.M., W.E. Redfoot, and D.A. Bagley. “Marine turtles of the central region of the Indian River Lagoon system, Florida”. *Florida Scientist* 70.4 (2007):415.

Ehrhart, L.M. and B.E. Witherington. 1987. Human and natural causes of marine turtle nest and hatchling mortality and their relationship to hatchling production on an important Florida nesting beach. Final Report, Project

Number GFC-84-018. Florida Game and Fresh Water Fish Commission, Nongame Wildlife Program, Technical Report No. 1. Tallahassee, Florida. 141 pages

Elko, N. and Mann, D. “Implementation of Geotextile T-Groins in Pinellas County, Florida” *Shore and Beach* 75.2 (2007): 1.

Ernest, R.G. and R.E. Martin. 1993. Sea turtle protection program performed in support ofvelocity cap repairs, Florida Power & Light Company St. Lucie Plant. Applied Biology, Inc., Jensen Beach, Florida. 51 pages.

Fergusson, I.K., L.J.V. Compagno, and M.A. Marks. “Predation by white sharks *Carcharodon carcharias* (Chondrichthyes: Lamnidae) upon chelonians, with new records from the Mediterranean Sea and a first record of the ocean sunfish *Mola mola* (Osteichthyes: Molidae) as stomach contents”. *Environmental Biology of Fishes* 58: (2000): 447.

Florida Fish and Wildlife Conservation Commission (FWC). “Guidelines For Marine Permit Holders” 2008.

Girard, C., Tucker, T. "Post-Nesting Migrations of Loggerhead Sea Turtles in the Gulf of Mexico: Dispersal in Highly Dynamic Conditions." *Marine Biology* 156.9 (2009): 1827.

*Hany,*J.L., K.L. Williams, and DA.Briscoe. Sex determination in loggerhead turtles: Differential expression of two hnRN Pproteins. *Development* 109 (1990):305.

Laurent, L., P. et al. “Molecular resolution of marine turtle stock composition in fishery bycatch: a case study in the Mediterranean”. *Molecular Ecology* 7:1 (1998): 529.

Limpus, C. et al. “Migration of Green and Loggerhead Turtles from Eastern Australian Rookeries. *Wildlife Research 19* (1992):347

Long, K.J. and B.A. Schroeder (editors). 2004. Proceedings of the International TechnicalExpert Workshop on Marine Turtle Bycatch in Longline Fisheries. U.S. Department ofCommerce, NOAA Technical Memorandum NMFS-F/OPR-26. 189 pages.

Lutz, P., Musick, J., Jeanette, W. 2003. The Biology of Sea Turtles V2. CRC Press: Boca Raton:Fl p288-298.

Mansfield, K.L. 2006. Sources of mortality, movements and behavior of sea turtles in Virginia. Unpublished Ph.D. dissertation. Virginia Institute of Marine Science, Gloucester Point, Virginia. 343 pages

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

Meylan, A. B. 1982. Estimation of population size in sea turtles, p. 135–138. *In:* Biology and conservation of sea turtles. K. A. Bjorndal (ed.). Smithsonian Institution Press, Washington, DC.

Meylan, A.; Schroder, B; Mosier, A. “ Sea turtle nesting activity in the state of Florida 1979-1992”. *Fla. Mar. Res. Publ*. 52. (1995): 51.

Milton, S. L. "Effects of Hurricane Andrew on the Sea Turtle Nesting Beaches of South Florida." *Bulletin of Marine Science* 54.3 (1994): 974.

Morreale, S.J. and E.A. Standora. Western North Atlantic waters: crucial developmental habitat for Kemp's ridley and loggerhead sea turtles. *Chelonian Conservation and Biology* 4 (2005): 872.

Mrosovsky, N. “Nocturnal emergence of hatchling sea turtles: control by thermalinhibition of activity”. *Nature* 220.5174 (1968): 1338.

Murphy, T. M., and S. Hopkins. 1984. Aerial and ground surveys of marine turtle nesting beaches in the Southeast Region, U.S. Final report to NOAA NMFS

Mrosovsky, N. “Nocturnal emergence of hatchling sea turtles: control by thermal inhibition of activity”. *Nature* 220.5174. (1968):1338.

National Research Council. 1990. Decline of the Sea Turtles: Causes and Prevention. National Academy Press, Washington, D.C. 259 pages

Nelson, D.A. and B. Blihovde. Nesting sea turtle response to beach scarps. Page 113 *in* Byles, R. and Y. Fernandez (compilers). Proceedings of the Sixteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum (1998).

NOAA Office of Protected Resources :Loggerhead Turtle (*Caretta caretta*). 2009 online www.nmsf.noa.gov

Pinellas County Coastal Management and Beach Nourishment. 2010 Online http://www.pinellascounty.org/environment/coastalMngmt/nourishment.htm

Pritchard, P. C. H. 2004. Long-term sea turtle nesting cycles in the Guianas. Pages 66–68 in M. S. Coyne and R. D. Clark, compilers. Proceedings of the 21st Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-528.

Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle.. National Marine Fisheries Service. (2008). Print.

Richards, P.M. 2007. Estimated takes of protected species in the commercial directed shark bottom longline fishery 2003, 2004, 2005. National Marine Fisheries Service, Southeast Fisheries Science Center Contribution PRD-06/07-08, June 2007. 21 pages.

Rumbold, D. G. "Estimating the Effect of Beach Nourishment on Caretta Caretta (Loggerhead Sea Turtle) Nesting." *Restoration Ecology* 9.3 (2001): 304.

Salmon, M. "Behavior of Loggerhead Sea Turtles on an Urban Beach. I. Correlates of Nest Placement." *Journal of Herpetology* 29.4 (1995): 560.

Schroeder, B. A., A. M. Foley, and D. A. Bagley. “Nesting patterns, reproductive migrations, and adult foraging areasof loggerhead turtles”. Smithsonian Institution Press, Washington, D.C., USA. (2003): 114

Seney, E.E. and J.A. Musick. “Historical diet analysis of loggerhead sea turtles (*Caretta caretta*) in Virginia”. *Copeia* 2 (2007): 478.

Silverman B. W. "Density Estimation for Statistics and Data Analysis". New York, Chapman Hall (1986)

Simpfendorfer, C.A., A.B. Goodreid, and R.B. McAuley. “Size, sex and geographic variation in the diet of the tiger shark, *Galeocerdo cuvier*, from Western Australia waters*”. Environmental Biology of Fishes* 61: (2001) 37.

Sobel, D. A photographic documentation of aborted nesting attempts due to lounge chairs. NOAA Technical Memorandum NMFS SEFSC (2000).

Steintz et al. “Beach Renourishment and Loggerhead Turtle Reproduction: A seven Year Study at Juniper Island Florida”. *Journal of Coastal Reserch* 14.3: (1998).

Tomas, J. "Marine Debris Ingestion in Loggerhead Sea Turtles, Caretta Caretta, from the Western Mediterranean." *Marine pollution bulletin* 44.3 (2002): 211.

Trindell, R., D. Arnold, K. Moody and B. Morford. 1998. Post-construction marine turtle nesting monitoring results on nourished beaches. Pages 77-92 in Tait, L.S. (compiler), Rethinking the Role of Structures in Shore Protection. - Proceedings of the 1998 National Conference on Beach Preservation Technology. Florida Shore and Beach Preservation Association, Tallahassee, Florida.

Tucker, A. D. "Eight Nests Recorded for a Loggerhead Turtle within One Season." *Marine Turtle Newsletter* 124 (2009): 16

Upham Beach Project Structural Alternatives Development and Analysys Report. Pinellas County Deparment of Environmental Management. Prepared by Coastal Planning and Enginering Inc. www.pinellascounty.org (2010).

Watson, J.W., S.P. Epperly, A.K. Shah, and D.G. Foster. “Fishing methods to reduce sea turtle mortality associated with pelagic longlines”. *Canadian Journal of Fisheries and Aquatic Sciences* 62 (2005): 965.

Weishampel, J. F. "Spatiotemporal Patterns of Annual Sea Turtle Nesting Behaviors Along an East Central Florida Beach." *Biological Conservation* 110.2 (2003): 295.

Witherington, B.E. “Ecology of neonate loggerhead turtles inhabiting lines of downwelling near a Gulf Stream front”. *Marine Biology* 140 (2002): 843.

Witherington, B., S. Hirama, and A. Mosier. 2006. Changes to armoring and other barriers to sea turtle nesting following severe hurricanes striking Florida beaches. A Final Project Report to the U.S. Fish and Wildlife Service. 11 pages.

Witherington, B. E. "Temporal Pattern of Nocturnal Emergence of Loggerhead Turtle Hatchlings from Natural Nests." *Copeia* 4 (1990): 1165.

Witherington, Blair; Kubilis, Paul; Brost, Beth; Meylan, Anne. 2009. “Decreasing annual nest counts in a globally important loggerhead sea turtle population” *Ecological Applications*, 19.1 (2009): 30.