The Effect of Nest Relocation and Beach Renourishment on the Loggerhead Sea Turtle (*Caretta caretta*) in Pinellas County, Florida

By

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Abstract: Loggerhead sea turtles (*Caretta caretta*) have major nesting sites along the protected shores of the southeastern United States, an area where the species are listed as either endangered or threatened. In this study, the effects of beach renourishment and nest relocation on the rate of emergence of Loggerhead sea turtle hatchlings from their nests. The study location was the beaches of Pinellas County, Florida; the study period was five years, 2006 through 2010. Because beach renourishment can be environmentally detrimental for sessile organisms such as sponges and coral, we hypothesized that beach renourishment would negatively affect hatchling success of the Loggerhead sea turtles. If the data supported our working hypothesis, then increased efforts to relocate Loggerhead sea turtles nests from renourished beaches to natural beaches would be justified. Contrary to our working hypothesis, this study found that the hatchling success of Loggerhead sea turtles was unaffected by nest relocation (leaving the nest in-situ versus relocating the nest), by beach type of origin (nest constructed by the Loggerhead sea turtles on natural beaches versus renourished beaches) or by the type of beach into which nests were relocated (natural beach versus renourished beach). Hatchling success was unaffected by relocating nests to less populated beaches to reduce light pollution or to higher ground to reduce to possibility of washout by high tides during storms. Ironically, our study of ~53,700 Loggerhead sea turtle hatchlings showed that they are capable of surviving the interventions of humans to save them. Additional studies of hatchling success in other Florida locations are needed before our results can be generalized to Loggerhead sea turtles within the southeastern United States.

Introduction

Loggerhead Sea Turtle Species Profile: Loggerhead sea turtles (*Caretta caretta*) are the most abundant sea turtle existing in the coastal waters of the United States (National Geographic). With major nesting areas along desirable coastal areas in the southeastern United States, eggs, hatchlings, and adults are also subject to frequent human interaction. Thus, Loggerheads have been listed as either an endangered or threatened species since 1978.

Loggerhead sea turtles are found worldwide in temperate and tropical ocean regions (NOAA Fisheries: Office of Protected Resources). They are the largest of the hard-shelled sea turtles (National Geographic). Their name, "Loggerhead", is a reflection of their powerful, crushing jaws and subsequently wide head. The average adult Loggerhead weighs between 200 and 250 pounds (90.7 and 113.4 kilograms) with a mean carapace length of around 36 inches (91 centimeters) (NOAA Fisheries: Office of Protected Resources). However, anomalies do exist; some have exceeded 1,000 pounds (453.6 kilograms) in weight (Department of Environmental Protection, State of Connecticut). Adults typically exhibit a reddish-brown carapace (dorsal shell) and yellow or tan plastron (ventral shell), an example of counter-shading, a camouflage technique used by many marine animals.

Although Loggerheads are omnivores throughout the course of their lives, the adult Loggerhead is primarily carnivorous. Using their robust jaws, Loggerhead sea turtles are able to eat many hard-shelled animals, such as crabs, clams, and snails, as well as softer prey, such as jellyfish. In general, sea turtles are non-discriminatory eaters. In a 2010 study, it was found that 35.2% of Loggerhead sea turtles examined had ingested marine debris, one of the many reasons nearly all sea turtle species, including the Loggerhead, are listed as either threaten or endangered

(Lazar & Gracan, 2010). Their non-discriminatory diet is one of the causes for the decline in sea turtle population.

Ingestible marine debris is not the only anthropogenic danger faced by the Loggerhead sea turtle. With very little threat from natural predators, human-induced fatalities are common within the species. Major hazards include incidental catch by fishing nets, lines, and trawls, entanglement in monofilament line and other marine pollution, and injury due to boat collisions. Threats to sea turtle nests and hatchlings exist as well. In many parts of the world, sea turtle eggs are harvested or nesting female sea turtle captured for their meat. In the United States, the greatest threat arises from the popularity of beaches, with renourishment projects and heavy tourist traffic disrupting nests and nesting females alike.

The major nesting sites of the Loggerhead sea turtle are located on the beaches of the southeastern United States, Australia, and Omar. These locations account for nearly 88% of the nesting population worldwide (NOAA Fisheries: Office of Protected Resources). In the United States alone, an estimated 68,000 to 90,000 nests are laid each year (NOAA Fisheries: Office of Protected Resources). Nests within the United States have an average clutch size of 100 to 126 eggs, each containing a hatchling that, once it has emerged, will weigh only 0.04 pounds (20 g). The area of focus within this study, Pinellas County, Florida, grosses around 100 nests each year. The majority of those nests are monitored by the Clearwater Marine Aquarium to promote nest protection and hatchling success.

Life Cycle of the Southeastern United States Population: Life is by no means easy for the Loggerhead sea turtle of the southeastern United States. Loggerhead hatchlings emerge at the same time from the nest and struggle down the beach towards the ocean. There are a number of threats on the beach. Artificial lights from condos, hotels, and streets can lead the hatchlings astray, causing them to become disoriented. Numerous predators exist on the beaches as well, waiting to devour newly hatched sea turtles. Gulls, terns, and other birds, along with scavengers, such as raccoons and rats, are attracted by the movement of the hatchlings. The hatchlings' best defense is safety in numbers and their instinctual demand to emerge at the same time from the nest and travel as one large group towards the ocean.

The first hours of the Loggerhead sea turtle's life is a frenzy of motion. After digging through nearly 1 meter (0.91 m) of sand and crawling up to 30.5 meters down the beach to the ocean, the Loggerhead will then swim frantically towards the protection of floating algal and seaweed clumps (Hays and Speakman, 1993). The floating material is commonly found between the Gulf Stream current and the coast of the southeastern United States, in areas where down wellings occur (NOAA Fisheries: Office of Protected Resources). This process can take the hatchling up to 48 hours.

While some hatchlings may linger off the coast of their natal beach, others will migrate across the entire Atlantic Ocean in an average of 5 years (Lohmann et.al 2001). In order to do so, the Loggerhead hatchlings utilize currents of the North Atlantic gyre. Recent research has shown that Loggerheads are able to sense the Earth's magnetic fields in order to navigate through the gyre; a navigational error taking the turtle too far north or south during their journey could prove fatal due to decreased sea temperatures (Lohmann, et.al, 2001).

The Loggerhead continues its trans-Atlantic migrations for the first 7 to 10 years of its life, maturing from a hatchling to a juvenile. Populations of juveniles are reported off the Azores and Madiera, spending much of their time in the top 5 meters of the water column. At the end of their migration period, juvenile Loggerheads will make their way closer to shore. From then on they are dependent on the abundant food and relatively warm and shallow areas of the neretic zone. Here, the Loggerheads will grow into adulthood, a journey that has takes them across the ocean and increases their weight nearly 6,000 times (NOAA Fisheries: Office of Protected Resources).

At around the age of 35, the female Loggerhead is sexually mature. She will mate with multiple males over a 3 month period before making her way towards the shores of her natal beach. While much is mentioned about the return of the female Loggerhead to the vicinity of her natal beach to nest, it should also be noted that male Loggerheads will migrate towards their natal beaches during the breeding season as well (Bowen, et. al 2004). During one nesting season, a mature female Loggerhead may lay from 1 to 7 nests, at intervals of approximately 14 days (U.S. Fish and Wildlife Service). The female may not nest again for up to 7 years, though, on average, she will mate and nest every 2 to 3 years (U.S. Fish and Wildlife Service).

The nests of the Loggerhead sea turtle are subject to many environmental and anthropogenic impacts, many of which can prove fatal to the entire clutch. The Loggerhead has adapted its nesting techniques to ensure a greater chance of success for the hatchlings, however, with the growth of the human population and the subsequent loss or transformation of natural nesting habitat, there is only so much the nesting female Loggerhead can do to protect the nest she will never again encounter. The hatchlings will emerge from the nest a mere 55 to 60 days following the deposition of the clutch into the nest, yet during that time they face the dangers of storm water inundation, predation, invasive vegetation, and human interference, among others (U.S. Fish and Wildlife Service).

Environmental Threats to Nests: Prior to the increase in human population and subsequent development of the southeastern United States' beaches and coastal habitats, environmental threats existed for the nests of the Loggerhead sea turtle. Although it has been thought that scavengers, ranging from the red imported fire ant (*Solenopsis invicta*) to the northern raccoon (*Procyon lotor*), feast upon the eggs and unborn hatchlings, a recent study found that fire ants scavenge on the remains of eggs after predation by raccoons and coyotes (Jaeson Clayborn, unpublished data). Meteorological events, such as flooding of beaches by high tides and hurricanes, can inundate nests with water, drowning them. Even area flora, like the invasive native Australian pine (*Casuarina equisetifolia*), can have an effect on the nests of the Loggerhead sea turtle.

The red imported fire ant (*Solenopsis invicta*) is an animal that is present on nearly all Florida beaches and would generally be of little concern to an adult Loggerhead sea turtle (Allen, et. al 2001). Yet, to newly hatched turtles, they can prove deadly. Studies conducted on red imported fire ants show that the insects burrow into 1% of the nests to feed upon the newly hatched sea turtles, waiting to emerge. Because sea turtles will wait until the majority of the nest has hatched and surface as a group, the fire ants are able to sting and kill many of the waiting hatchlings as well as those in pipped eggs (Allen, et. al 2001). In a study performed in 1997, a 15% decrease in hatchling emergence was noted in the few nests infected with red imported fire ants when compared to those without the insects present (Moulis, 1997).

Red imported fire ants are not the only insect species present on the beaches of the southeastern United States that cause problems for Loggerhead sea turtle nests and their hatchlings. The click beetle (*Lanelater sallei*) is a common North American species, found along the Gulf and Atlantic coasts (Donlan, et. al 2004). This species was noted interfering with and utilizing Loggerhead sea turtle nests as a source of food during their larval stages. In a 2003 study conducted on Key Biscayne, Florida, the click beetle was found to be more destructive towards the Loggerhead nests in a than its competing predators, the northern raccoon (*P. lotor*) and the ghost crab (*Ocypode quadrate*), combined. With a startling 44 nests disturbed and 298 eggs lost, the feeding habits of the larvae of the click beetle are both alarming and deadly. Infested nests exhibited an average of 6 eggs with holes of approximate 1/8 inch diameter that allowed the larvae to feed on the embryonic hatchlings, making the click beetle the study's deadliest predator.

As noted, insects are not the primary, predators on the majority of nests along the southeastern United States. Many different species of mammal excavate and feed on the eggs within Loggerhead sea turtle nests. The northern raccoon (*Procyon lotor*) is considered to be the leading predator of loggerhead sea turtle nests (Stancyk, et. al 1980) among the southeastern United States. Unlike other previously discussed predators, the northern raccoon will consume eggs from the nest at any time, including on the night of maternal deposition (Stancyk, et. al 1980). They are able to locate the nests using the scents of the adult female, as well as the eggs and depositional fluids produced during egg-laying. In a study conducted in 1977 on the beaches of South Carolina, the northern raccoon was responsible for the destruction of 95% of the Loggerhead sea turtle nests within a single season (Stancyk et al. 1980).

A fellow scavenger, the nine-banded armadillo (*Dasypus novemcintus*), is a secondary predator (Drennen, et al. 1989). The nine-banded armadillo benefits from and consumes what is left behind from the predatory efforts of the northern raccoon. In many cases of nine-banded armadillo predation on Loggerhead nests, evidence of previous raccoon foraging, as well as presence of the click beetle larvae are found (Drenne, et al. 1989). In many instances, it appears that the nine-banded armadillo is merely scavenging to "clean up" already devastated nests.

While predators are active threats to Loggerhead sea turtle nests within the southeastern United States, as well as worldwide, there are many more passive environmental perils, such as storm water inundation and vegetation, that the nests and their hatchlings must survive. Along the southeastern United States, large storms, such as hurricanes, are an annual threat that coincides with the nesting season of the Loggerhead sea turtle. In addition to exposing sea turtle nests to periods of water inundation, they cause rapid erosion-induced damages to the beaches themselves. While some vegetation may slow the transitions of erosion caused by the storms, other invasive plant species interfere with the natural development of hatchlings.

The coasts of the southeastern United States are accustomed to large storms, including hurricanes, bringing high winds and immense precipitation levels. As many residents do, Loggerhead sea turtles prepare for storm events when planning their nesting sites. While there is little the nesting female sea turtle can do to actively protect against storms, many excavate nests far back on the beach, near the vegetation line, to avoid potential storm surge events and to ensure their nest is placed on higher ground. Despite these efforts, however, many Loggerhead nests are devastated by the impacts of storms. The high waves and precipitation level caused by a large storm can drown the eggs or even wash them out into the ocean (Martin 1996). In addition to the drowning or wash-out caused by intense precipitation, impaction of sand can occur. The weight and tightly packed sand particles prevent an otherwise viable clutch of hatchlings from being able to dig through the sediment and emerge.

When Hurricane Erin passed through Florida's east coast, a study was conducted on 252 sea turtle nests. Of those, 95 were destroyed by the passage of the storm, which was ranked as a category one hurricane with maximum sustained winds of only 75 knots (Marin 1996). Reasons for the destruction of those 95 nests include decreased sand level, beach wash out, and subsequent scavenging and predation.

While some native vegetation does assist in holding sediment in place during periods of increased wind and wave activity, invasive species can cause many issues for the local flora and fauna. Such is the case for the Australian pine (C*asuarina equisetifolia*). Ironically enough, the Australian pine was brought to the beaches of the southeastern United States as hurricane protection, despite the species' now-known shallow rooting system. The tree is not adapted to hurricane-force winds and is therefore easily uprooted in stormy situations. This can cause an additional issue for the Loggerhead sea turtle, as uprooted trees change the temperature dynamics of the nearby sand, a sex-determining factor in the Loggerhead species (Schmid et al. 2008). Their decaying trunks as well take up key nesting habitat, preventing nesting female sea turtles from laying their nests in the critical beach front above high tide.

Anthropogenic Threats to Nests: Clearly the Loggerhead sea turtle faces many natural challenges during the critical nesting season. However, sea turtles have adapted to their ever-changing environment successfully for their nearly 200 million years of existence. Anthropogenic threats, however, are rapidly increasing, causing much of the decline in worldwide sea turtle populations across all 7 species living today. In the southeastern United States, nesting Loggerheads face the challenges nesting in beaches with artificial lighting, beach development, construction of counter-erosion structures, beach nourishment projects, and individual human activity.

The presence and amount of artificial lighting is a large consideration for the nesting female. While in some cases human development, such as beachfront condominium complexes, act as a shield from the artificial lighting of nearby streets, the light caused by largely urbanized beach settings cause issues for both the nesting female and her hatchlings. Studies have shown that nesting females will nest directly in front of buildings that shield the beach from artificial street lighting and avoid nesting in the illuminated gaps in between (Salmon 2003). This selection may be based partly upon the female's desire to build a nest that will be protected from nocturnal scavengers or predators.

Upon emergence from the nest, the presence of artificial light may disorient sea turtle hatchlings. Hatchlings use mainly visual cues to establish their surroundings. By avoiding larger objects, such as dunes or, from a more modern standpoint, human development, the sea turtles are generally driven in the correct direction. Without large objects in their path, the sea turtle hatchlings travel towards the reflective light of the celestial bodies portrayed across the ocean (Salmon 2006). The addition of artificial light may confuse the sea turtle hatchlings. The brighter artificial light outshines the dimmer light reflection onto the ocean, causing hatchlings to travel instead towards the manmade source. The artificial source causes the hatchlings to spend more time wandering on the beach, leaving predators a larger time window to devour the hatchlings. Just as deadly, the manmade light could lead sea turtle hatchlings onto towards development, such as beach construction or busy roads.

The increase in urban development and human interest in the coastlines of the southeastern United States has caused a subsequent boost in tourism and population. Many decisions are therefore made to halt the erosion of these areas and continue the economic boom caused by the "permanent" manmade structures. To combat erosion and maintain wide, sandy beaches for tourist activities, beach nourishment is a common practice. While at first one might think that beach nourishment also preserves the nesting habitat of the Loggerhead sea turtle, as well as the beaches for human activity, many times this is not the case.

Although many beach nourishment projects require environmental assessments prior to and during their work, differences in sediment, including mineral ratios and density, affect the nesting selection of the Loggerhead sea turtle (Rumbold, et. al 2001). Such changes impact the ability of the nesting female to dig the appropriate nest cavity, as well as the ability of the hatchlings to surface. Within the nest, temperature variations caused by the changes in sediment density and therefore heat transfer can also affect the sex ratio of the clutch, a factor determined during development.

Beach nourishment projects also increase the amount of false crawls within a given season. A false crawl is when a female sea turtle emerges from the ocean and explores the beach without actually laying a viable nest. This can be caused by disorientation or fear of her surroundings. One study conducted on the Atlantic coast of Florida showed false crawls had increased nearly 50% during the nourishment project (Rumbold et al. 2001). While the number eventually decreased in the following years along the same beach, the initial season was greatly affected by the nourishment project.

Beach armoring, the construction of seawalls, groins, and jetties, presents another limitation for nesting females and hatchlings. While the hatchlings may be less likely or able to travel inshore due to the presence of physical obstacles, they may also increase the chance of storm water inundation (Rush 2003). The construction of seawalls along beaches to protect property limits the nest site selection for many nesting females, as well. With increasingly smaller beach front year after year, the female is forced to nest closer to the high tide line, again increasing the chance of drowning the nest through seawater inundation.

Nesting Management Solutions: Due to the natural and increasing anthropogenic threats to sea turtle nests, there are many nest management programs throughout the southeastern United States, as well as worldwide, to ensure that this endangered species does not go extinct. With much of the Loggerhead sea turtles' life is spent swimming in the oceans, the most effective way to protect the sea turtle is to protect the nests and hatchlings during the incubation period. There are many methods to managing Loggerhead nests, including nest patrols and education, nest caging, and the controversial relocation of nests.

Nest caging can help to prevent human disturbances (Kornaricka et al. 2006). In some cases, cages are also designed to help protect hatchlings against terrestrial predators. Another possible benefit of caging nests is the increased awareness of sea turtle nesting locations among the local and visiting human populations. The obvious visibility of a caged nest can peak the interest of someone who potentially would not have otherwise known of the existence of sea turtle nests in the area.

Public education is also an effective method of nest management. While nest caging and relocation can be effective in the short-term for increasing hatchling success, there is always the possibility that nests will be missed or overlooked, therefore not receiving the protection of their neighboring nests (Witherington and Martin 2003). This causes the overlooked hatchlings to be subject to all the threats that caging and relocation are meant to protect against. Educating the public about the importance of sea turtle awareness by encouraging proper beach lighting, cleaning up beach furniture, and decreasing beach obstructions can help to protect the nests that otherwise may have been prone to reduced success. Increased education may also help to create new legislation which could benefit future generations of nesting females and hatchlings alike.

In this study, the effects of nest relocation on the survival of hatchlings were determined. By examining nest relocation data from the beaches of Pinellas County, Florida, a greater understanding and comprehensive case study of the implications of human interaction, both positive and negative, can be achieved. Nest relocation is a term used to describe the removal of in-situ sea turtle eggs from their natural-made nest to either another field location or, in extreme cases, a manmade hatchery. Relocation efforts are typically due to a predicted decrease in survival chances for the hatchlings, either by natural or anthropogenic occurrences, such as the aforementioned predation, climatic disturbances or habitat alteration. However, there are inherent risks in the movement of sea turtle eggs, such as death of the embryo upon transport and skewing the hatchling sex ratio due to climactic changes of the nesting site (Witherington and Martin 2003).

Nest relocation typically occurs within 2 to 12 hours of oviposition, which means that nest relocations most often occur at night, under conditions of reduced visibility for the nest manager (Abella et al. 2010). During nest relocation, eggs must be kept in their same vertical orientation to prevent membrane disruption and measurements must be taken to make sure that the manmade nest is of the correct depth and width to accommodate the eggs. To avoid membrane disruption, in many cases, eggs are marked with graphite to designate an upward facing and downward facing position as the egg is pulled from the natural nest. In a study conducted in Africa, delayed relocation of the nests up to 96 hours post-oviposition has shown no delay of embryonic developed or evidence of reduced hatchling success, suggesting that the nest manager can take more time to successfully locate, unearth, and safely transport the eggs to another location (2010).

Methods

Artificial Hatcheries and Individual Translocation: Artificial hatcheries for the relocation of sea turtle eggs from their natal nest site are located either on the beach or, less commonly, in a laboratory setting. These areas are typically located close to or on the natal beach, but consist of multiple groupings of eggs relocated to the same area. Artificial hatcheries are located above the high tide line and are typically fenced off to avoid both human and predator disturbances. These areas typically have nests of uniform width and depth, despite the natural nest conditions. In some cases, the nests are also individually caged, in addition to the protective fencing of the hatchery itself (Andrew et al. 2003).

Artificial hatcheries offer many advantages to sea turtle hatchlings. Predation rates are dramatically diminished and success rates of the hatchlings can be determined (Andrew et al. 2003). In addition, hatcheries do provide a site for increased environmental education, using sea turtle nests and new hatchlings as educational ambassadors to their species (2003). It can be argued, however, that detaining hatchlings for educational purposes has negative effects on the imprinting and long-term success of the turtle.

Some studies have shown that incubation periods are longer in artificial hatcheries than in natural nests (Abella et al. 2010). This can lead to a skewing of the sex ratio of the hatchlings towards a greater number of females. The longer incubation period and skewing of the ratio is hypothesized to be due to depth of the nest. In a study on success rates in artificial hatcheries performed in Africa, artificial nests were uniformly 50 cm deep, whereas natural nests vary in depth and width (2010).

Another disadvantage of large hatcheries is money; large hatcheries tend to be costly as they require a fenced location and trained personnel (Andrew et al. 2003). In addition, there is no guarantee that the hatchling success rate will be any greater. In many cases, despite decreased nest predation, hatchling mortality is often higher in hatchery situations. This is because controlled releases of groups of hatchlings can cause an increase in the number of predators, both terrestrial and marine, that feed upon the turtles as they make their way down the beach and into the ocean (2003).

On a smaller scale, some beach hatchery efforts encompass the relocation of nests on an individual basis. Nests are evaluated for their vulnerability on a case-by-case basis and moved a short distance to increase the chances of hatchling survival. While these less drastic moves can be just as dangerous for the hatchlings from a nest predation standpoint, they can help to prevent in disorientation from lighting, human disturbances either accidental or from poaching efforts, and better protection from storm surge and extreme high tide. The nests are also more readily studied and monitored for success, as the eggs are countable and success rates can be measured. Just as with large scale hatcheries, however, individual nest translocation efforts still afford many dangers to the hatchlings, such as membrane dislocation, incorrect nest measurements, decreased embryonic development, or increased hatchling mortality.

Transplantation: Transplantation is a method of removing hatchlings from their nest site prior to or just following emergence. In some cases, transplantation can be done to prevent high levels of predation at any one site (Baskale and Kaska 2001). Transplanted hatchlings are taken from their natural nest site and released at predetermined sites to avoid a build-up of predators or avoid washout due to proximity to the mean high water line. Another reason for transplanting hatchlings is reduced light disorientation upon hatching. This measure can be seen as a less drastic version of relocation, saving the hatchling from the risk of embryonic death during transport and skewed sex ratios as they are left to develop in their natural nest site.

Study Location 2006 to 2010: Pinellas County is a peninsular landmass located on the western coast of Florida. Surrounded on either side by water, Pinellas County has approximately 58 miles of coastline, 35 of which are along the Gulf of Mexico (Coastal Management). Of these 35 miles, 26 are patrolled by Clearwater Marine Aquarium, a non-profit organization that acts as a marine animal hospital for many species, including the Loggerhead sea turtle (Clearwater Marine Aquarium). From the months of April to October, Clearwater Marine Aquarium's Sea Turtle Nesting Patrol team, composed of both trained staff and volunteers check the Gulf beaches each morning for signs of sea turtle activity.

Sea turtle tracks are identified by a number of different methods. The Loggerhead sea turtle is known for creating asymmetrical marks, caused by the alternating movement of the forelimbs (Andrews et al. 2003). Their body creates a wide, but shallow depression of about 70 to 90 centimeters behind which there is rarely a tail mark (2003). The nests themselves can typically be identified from the disrupted sand, flung by the nesting female as she buried her nest.

In order for Clearwater Marine Aquarium to relocate a nest, the nest must be deemed otherwise "doomed", typically due to proximity to the mean high water. If a nest's proximity to this line causes nest managers to think the nest will be inundated or washed out, the nest will be relocated to a more suitable area within Clearwater Marine Aquarium's 26 mile range.

Pinellas County's consistent Loggerhead nesting population offered data over a five-year span that allowed for research on the effects of lighting, beach renourishment projects, and relocation of nests post-oviposition on the incubation, hatchling success, and emergence success of Loggerhead sea turtle hatchlings. By examining the data, inferences can be made concerning the overall human impact, both positive and negative, on Pinellas County's nesting Loggerhead population. Data was taken from Clearwater Marine Aquarium's Sea Turtle Nesting Patrol from the year 2006 to the year 2010.

Clearwater Marine Aquarium Nest Data Collection: Nests are identified by the characteristic tracks of the Loggerhead sea turtle. GPS locations of each nest are recorded. Measurements are taken from the assumed center of the nest to the mean high water line for the beach and from the assumed center of the nest to the nearest line of vegetation. Beach observations, such as whether the beach is natural or renourished and the amount of potential light pollution, are also recorded. A renourished beach is one in which sand and sediment has been dredged from a different location and added to the natural sediment of the beach. The renourished beaches can sometimes have a different width and sediment grain than the natural beach. If a nest is deemed "doomed" in its current natal or "in-situ" location, it is relocated. For relocation, the sea turtle eggs are removed from the nest, counted, and marked to show vertical orientation. They are placed in a container and moved to a nearby location where the conditions are thought to provide a greater chance of hatchling success. Once a nest is relocated, new measurements for GPS, mean high water line, and vegetation line are collected and new beach observations are recorded. These measurements and observations are noted in a database. Continued observations, such as markings of predation or inundation with water, are collected throughout the incubation period. After a nest has hatched, total eggs, hatched eggs, piped eggs, and any fatalities are counted. This updated information is added into the standing database. The collected data is analyzed for each nest, examining hatchling success rates and emergence success rates. The hatchling success rate is calculated by examining the number of hatched eggs by the number of total eggs. The emergence success rate is calculated by examining the number of hatched eggs by the number of hatchlings that emerged from the nest.

Data Analysis: Statistical tests require that data have a central tendency, most often described as a normal distribution. Most of our data were normally distributed. Statistical tests are forgiving of slightly skewed distributions when the sample size is large (greater than 100). Our total sample size included 517 Loggerhead sea turtle nests, thus we used parametric tests when appropriate. The data were tested for normality of the distribution. Pending on the type of data and the number of variables, Chi-square, regression, t-test, or ANOVA were used.

Results

Number of nests per month: The majority of nests (84%) were constructed in June and July (Fig. 1).

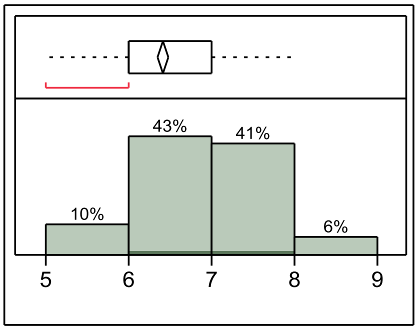


Figure 1: Percent of nests per month (n = 517).

Number of nests per year: In 2007, the number of nests constructed was three times smaller than in the other years of the study (Fig. 2).

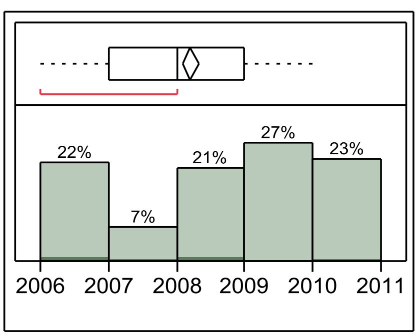


Figure 2: Percent of nests per year (n = 517).

Distance of nests to mean high water line: Nests that were relocated were significantly closer to the mean high water line than nests that were left in-situ (Fig. 3; t-test: t = -7.5067; p <.0001). The mean distance from mean high water line for nests left in-situ was 18.3 m; the mean distance from mean high water line for later relocated nests was 10.7 m. Thus, relocation added a 7.6 meter margin-of-safety for sea turtle eggs and hatchlings from storm surges that might otherwise flood nests.

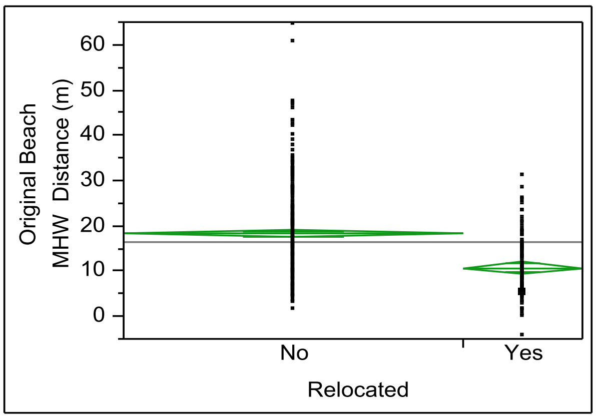


Figure 3: Constructed nest distance to mean high water line (n = 515).

Distance of nests to vegetation line: Nests were left in-situ were significantly closer to the vegetation line (Fig. 4; t=test: t = 9.9277; p = 0.0007). The mean distance from the vegetation line for nests left in-situ was 16.5 m; the mean distance from the vegetation line for relocated nests was 26.4 m. Relocation moved nests on average, 9.9 m closer to the vegetative line and away from the high tides of storm surges.

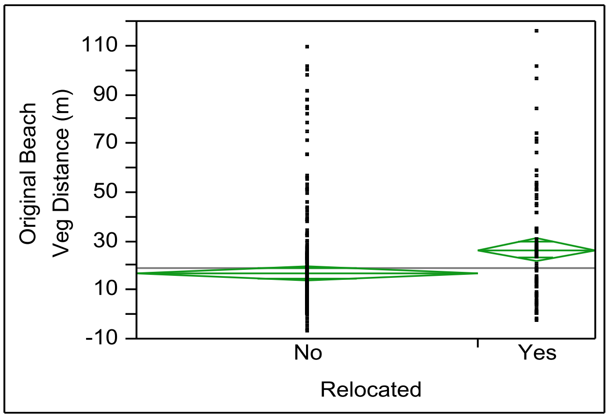


Figure 4: Constructed nest distance to vegetation line (n = 327).

Incubation Period: No significant difference was found in the incubation period between in-situ nests and relocated nests (Fig. 5; t-test: t = 0.4936, p = 0.3983). The mean incubation period for nests left in-situ was 53.8 days; the mean incubation period for relocated nests was 54.3 days.

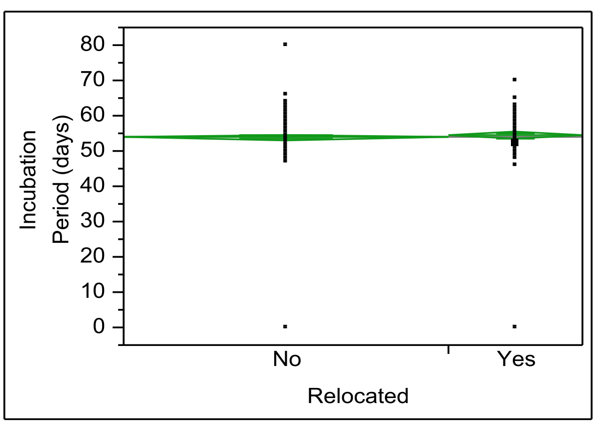


Figure 5: Comparison of incubation period between in-situ and relocated nests (n = 441).

Clutch Size: A significant difference was found between the clutch sizes of nests left in-situ and relocated nests (Fig. 6; t-test: t = 4.92127, p = 0.0228). The mean clutch size for nests left in-situ was 102.7 eggs; the mean clutch size for relocated nests was 107.6 eggs. This difference might not be meaningful from a Loggerhead sea turtle perspective.

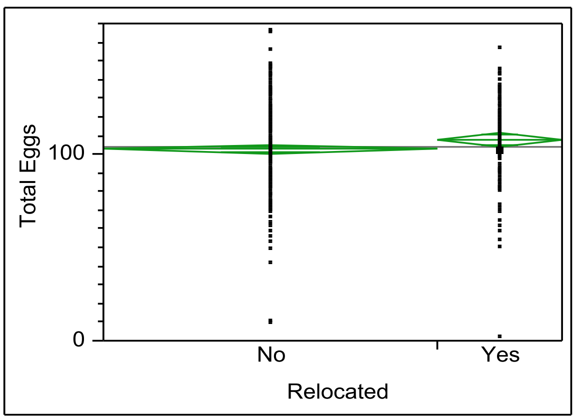
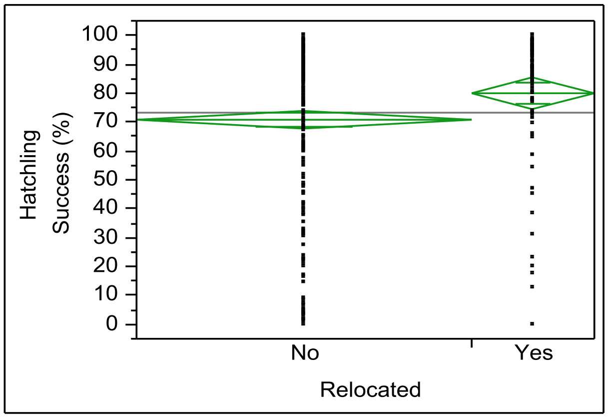


Figure 6: Comparison of clutch size between in-situ and relocated nests (n = 492).

Hatchling Emergence and Survival by Nest Relocation: A significant difference was found in the percentage of hatchling survival between in-situ nests and relocated nests (Fig. 7a; t-test: t = 9.26, p = 0.0039). The mean hatchling survival for relocated nests was ~10% higher than for in-situ nests (80.1% versus 70.8%). The emergence of hatchlings from their eggs was significantly higher for relocated nests than for in-situ nests (Fig. 7b; t-test: t = 8.50; p = 0.0098). The mean emergence of hatchlings from eggs was ~10% higher in relocated nests than in in-situ nests (79.9% versus 68.8%). For relocated nests (n = 132 nests out of 491), the ~10% gain in hatchling survival combined with the ~10% gain in hatchling emergence from eggs resulted in 5.4% increase in the survival for Loggerhead sea turtle hatchlings.



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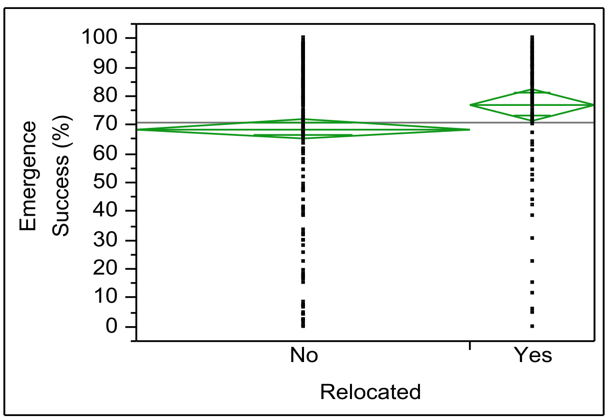

b

Figure 7: Comparison of percentage of hatchling emergence and survival between in-situ and relocated nests. (a) Hatchling survival was significantly greater in relocated nests. (b) Likewise, the percent emergence of hatchlings from eggs inside the nest was significantly greater in relocated nests than in in-situ nests (n = 491).

Hatchling Success by Inundation: A significant difference in the percentage of hatchling success was found between nests that were known to be inundated with water and nests that were not (Fig. 8; t-test: $t = -44.841$, $p < .0001$). Nearly half of the hatchlings were drowned (44.8%) when nests were flooded during storm surges (inundated nests = 81.3%; non-inundated nests = 36.5%).

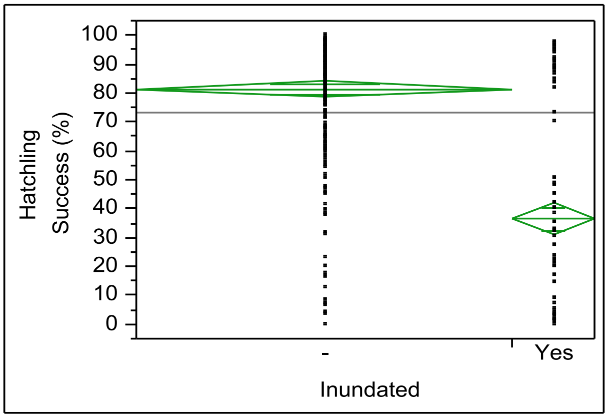

Figure 8: Comparison of percentage of hatchling success between inundated and non-inundated nests (n = 491).

Rate of Relocation by Month: No significant difference was found in the number of relocated nests by month (Likelihood Ratio: $\chi^2 = 5.948$, $p = 0.1142$).

Rate of Relocation by Year: A significant difference was found in the number of relocated nests by year (Fig. 9; Likelihood Ratio: $\chi^2 = 75.443$, $p < .0001$). The number of relocated nests was significantly higher for years 2006 and 2008.

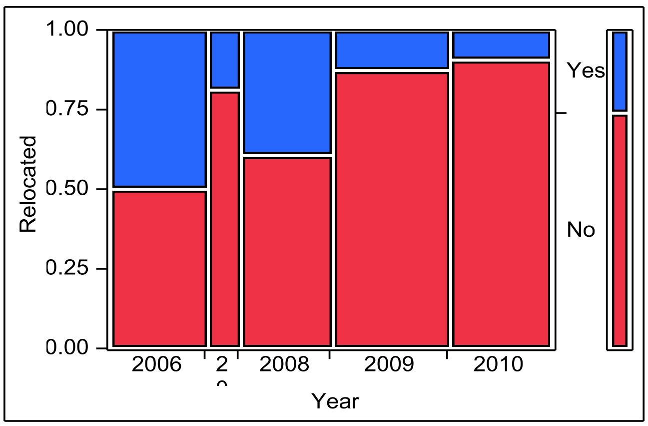

Figure 9: The number of relocated nests by year (n = 517).

Rate of relocated nest by beach status: No significant difference was found in the rate of relocation between natural and renourished beaches (Fig. 10; Likelihood Ratio: $\chi^2 = 2.283$, $p = 0.1308$).

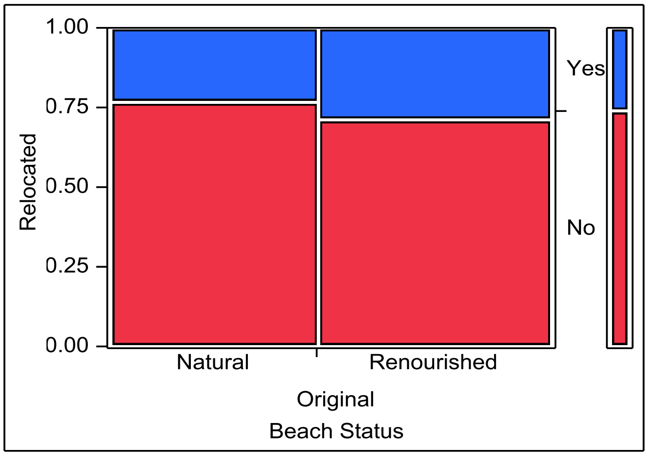

Figure 10: The rate of relocation by beach status (n = 517).

Hatchling Success by Relocation, Status of Original Beach, and Status of Relocated Beach: No significant difference was found in percentage of hatchling success based on nest relocation, status of original beach (natural or renourished), or status of relocated beach (natural or renourished) (Three-way ANOVA; $F_{3, 127} = 0.24$, p = 0.870).

Emergence Success by Relocation, Status of Original Beach, Status of Relocated Beach and Year: No significant difference as found in percentage of emergence success based on nest relocation, status of original beach (natural or renourished), status of relocated beach (natural or renourished), or year (Four-way ANOVA; $F_{4, 101} = 1.37$, p = 0.256).

Discussion

A five year study of nesting by Loggerhead sea turtles in Pinellas County, Florida found that relocating nests significantly improved the survival of hatchlings emerging from the eggs inside the nest and for hatchlings emerging from the nests after hatching. Surprisingly, the survival of hatchlings was not affected by whether the nest was constructed by the sea turtle on natural or renourished beaches or whether nests were relocated by humans to natural or renourished beaches. Another surprising finding was that the incubation period was unaffected by nests that were left in situ compared to those that were relocated. Other studies (unpublished data) in other locations in Florida found that relocation helped and harmed hatchling success. Relocated nests were less likely to be inundated by storm surges but were more likely to be predated by raccoons. Finally, a significant portion of hatchlings died (44.5%) when nests were inundation from storm surges.

In conclusion, this five year study of ~53,700 Loggerhead sea turtle hatchlings from 517 nests constructed in Pinellas County, Florida over a five-year period showed that, when nests were relocated, ~10% more hatchlings survived in the nest; of those survivors, ~10% survived the emergence from the nest itself. However, relocating nests did not prevent deaths from storm surges. Nor were hatchlings adversely affected by beach renourishment. Coninued long-term studies should be conducted both within Pinellas County and beyond to discover the overall effects of nest relocation on this endangered species of sea turtle.

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