

**EFFECTS OF A SHORE PROTECTION PROJECT ON  
LOGGERHEAD AND GREEN TURTLE NESTING ACTIVITY AND  
REPRODUCTION IN BREVARD COUNTY, FLORIDA**

by

KELLY A. BROCK  
B.S. Florida State University, 2000

A thesis submitted in partial fulfillment of the requirements  
for the degree of Master of Science  
in the Department of Biology  
in the College of Arts and Sciences  
at the University of Central Florida  
Orlando, Florida

Spring Term  
2005

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## ABSTRACT

Marine turtle reproductive success is strongly correlated with the stability and quality of the nesting environment. Because females show fidelity to key nesting beaches, the management and physical characteristics of these beaches directly affect future generations of marine turtles and may be essential for the recovery of these threatened and endangered species.

The impacts of beach restoration on loggerhead turtles (*Caretta caretta*) and on green turtles (*Chelonia mydas*) were investigated. Previous studies concerning beach nourishment projects have focused on loggerhead turtles. I compared data between nourished and non-nourished areas and between loggerhead and green turtles. I found, at one season post-nourishment, negative effects on nesting success and no significant effect on reproductive success for both loggerheads and established the same relationships with green turtles. Physical attributes of the fill sand, which did not facilitate acute scarp formation or severe compaction, did not physically impede turtles in their attempts to nest. Instead, the decrease in nesting success was attributed to an absence of abiotic and or biotic factors that cue nesting behavior. The increase in loggerhead nesting success rates

during the second season post-nourishment was attributed to the equilibration process of the seaward crest of the berm.

After the beach was restored, both species of turtles placed nests significantly farther from the water in the nourished area than in the non-nourished area. Green turtles nested on or near the dune and loggerheads nested on the seaward crest of the berm. The tendency of loggerheads to nest closer to the water resulted in more loggerhead than green turtle nests being “washed out” by erosion during the equilibration process. There was a significant increase in hatching success only for loggerheads when wash outs were excluded, thus illustrating the importance of nest placement and the detrimental effects of the equilibration process to the reproductive success of loggerheads. A decrease in reproductive output occurred during the first season post-nourishment. The reduction in the estimated total number of hatchlings produced (reproductive output) was a consequence of decreased nesting success lowering nest numbers. This reduction demonstrates that, regardless of similar reproductive success rates, marine turtles incurred net losses during the first season following nourishment. These results further reveal the impacts of decreased nesting success and the importance of minimizing excessive non-nesting emergences associated with beach nourishment.

## **ACKNOWLEDGMENTS**

This research was funded by Brevard County Office of Natural Resources Management and the U.S. Fish and Wildlife Service. Previous funding that contributed to the preliminary data of this study was made possible by contributions from World Wildlife Fund-US, NOAA National Marine Fisheries Service, Indian River Audubon Society, U.S. Army Corps of Engineers, and Aquarina. The Richard K. Mellon Foundation is acknowledged for in kind support. Don George of Geomar Environmental Consultants, Inc. and Bob Ernst and Erik Martin of Ecological Consultants, Inc. provided helpful comments in developing this study. The UCF Marine Turtle Research Group, Joshua Reece and Eliza Gilbert contributed to the efforts put forth during this study.

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## **LIST OF ABBREVIATIONS**

ES- Emerging success  
FDEP- Florida Department of Environmental Protection  
HS- Hatching success  
MHWL- Mean high water line  
NS- Nesting success  
RO- Reproductive output  
sCL- Straight carapace length

## INTRODUCTION

For oviparous species the habitat in which eggs are deposited strongly influences offspring survival and thus may have important consequences for the reproductive success of the adult (Martin, 1988; Hays and Speakman, 1993). The marine turtle evolved secondarily to an aquatic existence and possess many adaptations for the species-habitat relationship (Ehrhart, 1998). All marine turtles have modified limbs or flippers that are well suited for swimming but poorly adapted for terrestrial locomotion. However, as a result of retaining an oviparous reproductive strategy, their survival depends on a terrestrial environment in which to nest (Pritchard, 1997).

Reproductively active marine turtles typically exhibit nest site fidelity to beaches that over evolutionary time, have possessed characteristics conducive to successful nesting (Carr, 1986; Witherington, 1986; Bowen et al., 1992; Bowen, 1995; Weishampel et al., 2003); The benefits of this behavior outweigh the benefits of random beach selection and result in relatively high reproductive success and offspring survival (Bjorndal and Bolten, 1992; Crain et al., 1995). Considering that reproductive success is strongly correlated with the nesting

environment and that females show fidelity to nesting beaches, the management and quality of the coastal ecosystems at these beaches directly affect future generations of marine turtles and are essential for the recovery and management of these threatened and endangered species.

Habitat alteration within an ecosystem is often a major cause of reduction of species diversity (Ehrenfeld, 1970). Alterations to the environment occur naturally but are often interfered with, impeded by, or accelerated by human populations (Southwick, 1996). Coastal ecosystems are compromised by erosion, the response to severe storms and sea level rise. During these events the shoreline retreats (Walton, 1978). This natural recession is often exacerbated by artificial navigational inlets which prevent the littoral transport and accretion of sands (Douglas, 2002; Kriebel et al., 2003). Conversely, it is impeded by urban development as it generates threatening conditions to man-made structures and recreation (Pilkey, 1991; Olsen and Bodge, 1991). Collectively, these disparate pressures lead to the reduction of nesting habitat for marine turtles.

The steeply sloped Atlantic beaches of east central Florida are historically important nesting grounds for significant populations of threatened and endangered marine turtle species (Carr and Carr, 1978; Huff et al., 1980; Provanca and Ehrhart, 1987; Ehrhart et al., 2003). While naturally suitable for nesting, the beaches are subject to instability and accelerated rates of erosion

(Bruun, 1962). The Department of Environmental Protection, Bureau of Beaches and Coastal Systems identifies many of these beaches as “critically eroded”. This designation, has led to the development of a comprehensive long-term management plan for the restoration and maintenance of such beaches. The impacts of severe beach erosion upon coastal ecosystems can be mitigated by inland retreat of human development, coastal armoring (i.e. seawalls or rock revetments) and beach restoration projects (Douglas, 2002). Although a retreat of human development is the most logical in the long term, at present it is politically unrealistic, and due to the detrimental effects of coastal armoring which leads to the elimination of the beach, beach restoration is currently the acceptable engineering solution for shoreline protection (Lucas and Parkinson, 2002).

The preferred and most effective strategy for beach restoration, as termed by engineers and coastal geologists, is beach nourishment. Beach nourishment is the mechanical placement of large quantities of sand on a beach to counteract erosion by advancing the shoreline seaward or by building up a dune (Dean, 2002). The process extends the life expectancy of urban areas, revitalizes recreation and allows ecological functions to continue (Lucas and Parkinson, 2002). Beach nourishment projects have been employed to restore and maintain many beaches in which erosion had critically threatened or eliminated habitat for threatened and endangered species, i.e., beach mice, marine turtles, piping

plovers, and numerous plant species (Committee on Beach Nourishment and Protection, 1995). The protection and preservation of habitat has allowed beach restoration projects to become useful conservation techniques for coastal ecosystem management. As a result, beach nourishment may prove to be pertinent in maintaining the Atlantic beaches of east central Florida as critical nesting grounds essential to the survival of marine turtles.

Nourishment projects modify the abiotic and biotic components of the ecosystem and have the potential to cause substantial changes to the biota in the area. The effects can be detrimental or beneficial and can be both short and long-term depending on the nature of the system present (Dean, 2002). Technological advances in the mechanisms of beach nourishment have reduced many of the potentially negative impacts to marine turtles. In Florida, restoration activities must be conducted outside of the marine turtle nesting season (i.e. November to April), give special attention to the design template of the nourishment profile, and use fill materials that consist of sediments with physical attributes comparable to those of the native beach. Beach nourishment projects modify numerous abiotic components of nesting beaches, thereby potentially influencing the outcomes associated with nesting and reproductive success. It follows that a crucial requirement for evaluating the success of beach restoration projects for marine turtles is to determine the effects of these projects on nesting and reproductive success.

Most of the previous studies and generalizations concerning beach nourishment projects have been based upon the impacts on loggerhead turtles (Fletemeyer, 1984; Raymond, 1984; Nelson and Dickerson, 1989; Ryder, 1993; Bagley et al., 1994; Crain et al., 1995; Milton et al., 1997; Steinitz et al., 1998; Trindell et al., 1998; Davis et al., 1999; Ecological Associates, Inc., 1999; Herren, 1999; Rumbold et al., 2001). Documented effects on green turtles have not been reported using statistically significant sample sizes and do not include results from the first nesting season after project completion (Palm Beach County Department of Environmental Resources Management, 2001). Large economic investments are made in the biological monitoring requirements of beach nourishment projects. If green turtles and loggerhead turtles respond similarly to the nourishment and demonstrate similar effects then it is possible that monitoring requirements and sampling strategies can be reduced and would not need to be as labor intensive.

The purpose of this study was to describe the effects of current beach nourishment practices on populations of nesting loggerheads and green turtles. The objectives included: 1) assessing total nesting, nesting success, and nest placement; 2) accounting for effects on reproductive success by determining hatching and emerging success of deposited nests 3) estimating total reproductive output to determine if a net cost or benefit was incurred and 4)

quantify observable effects to post-emergence hatchlings. By using pre- and post-nourishment comparisons to adjacent non-nourished (natural) beaches, I was able to distinguish between direct effects caused by the nourishment project and annual fluctuations and natural patterns.

## **METHODOLOGY**

### BIOLOGY OF THE STUDY ANIMALS

In general, loggerhead turtles favor steeply-sloped, moderate to high energy beaches with gradually-sloped offshore approaches (Provanca and Ehrhart 1987). Green turtles typically nest on steep, high energy beaches, where a deep nest cavity can be dug above the high water line. Nesting habitats frequently overlap and the two species may be found nesting on the same beaches. In the United States, loggerhead nests greatly outnumber green turtle nests, but green turtles still nest in significant numbers. These green turtles exhibit a high/low biennial pattern in nest production and have done so since at least 1989. Even numbered years (i.e. 2000, 2002) experience a high number of nests while odd numbered years (i.e. 1999, 2001) show low nest production. From 1989 to 2003,

the estimated annual number of loggerhead nests has fluctuated without a conspicuous trend (Weishampel et al., 2004).

Nest measurements and clutch depth for each species correlate with several measurements of the size of the female (Carthy et al., in review). Mean straight carapace length (sCL) for nesting loggerheads is about 92 cm; corresponding mean body mass is about 113 kg, whereas the mean for nesting green turtles is 99 cm sCL and 136 kg body mass (Witherington and Ehrhart 1989). As a result, green turtle nests are larger and deposited at greater depths than loggerhead nests.

All species of marine turtles share a core sequence of nesting behaviors. Descriptions of the behavioral sequences have been given in detail by Miller et al. (2003). Female turtles emerge on nesting beaches at night to deposit eggs; the process takes an average of two hours. While on the nesting beach, adult females and hatchlings orient toward the ocean using photic cues (Witherington and Martin, 2000). In the United States, loggerhead turtles begin nesting in late April and continue until early September, while green turtle nesting season runs from late May through October. Individuals lay 4 to 7 nests per season, approximately 12 to 14 days apart. The average number of eggs per clutch is 113 for loggerheads and green turtles average approximately 130 eggs. The eggs incubate for 50 to 60 days. Natural hatching success of undisturbed nests is

usually high, rates over 50 percent are commonly reported (NMFS and FWS 1991a, 1991b).

### STUDY SITES

This study was conducted on a 40.5 km stretch of beach located on the central east coast of Florida, in southern Brevard County, bordered to the north by Patrick Air Force Base, and with the southern region comprising the Archie Carr National Wildlife Refuge. A centrally located five-kilometer portion of this area was nourished from February through April 2002, prior to the 2002 marine turtle nesting season (officially May 1 to October 31). The northernmost reach of the project was near the center of the Town of Indialantic, Florida Department of Environmental Protection (FDEP) Monument R-122.5, and extended southward to Melbourne Beach, FDEP Monument R-139 (Figure 1).

Physical monitoring studies of the nourishment project are summarized as follows to provide details of the alterations to the beach profile and sand composition. Fill material consisting of approximately 917,000 cubic meters of sand obtained from offshore sources was pumped onto the beach using a hydraulic pipeline dredge. Bulldozers were used to manipulate the fill, forming a constructed berm that extended 34.5 m, on average, from the natural berm and advanced the mean high water line (MHWL) seaward an average of 37.1 m. The

new berm profile was elevated 3.1-3.3 m above the mean low water line (MLWL) and is characterized as being flat with no constructed slope. Along the landward portion of the berm a small dune feature was constructed and the seaward edge of the berm was constructed to have a 1:15 slope throughout the entire project. With the exception of coarse grain size fraction (>1mm) being 5 to 10 percent higher (Olsen Associates, Inc., 2003a), the geotechnical characteristics of the fill material were comparable to native sand as described by grain size sieve analyses, visual estimates of shell content, and high-temperature carbonate burn tests. The nourished beach had a higher percentage of acutely shaped grains, whereas the natural beach consists of a higher percentage of rounded and worn grains. Sediment color used for fill materials is not part of the permit monitoring requirements, but a visual comparison indicated that following deposition the fill material was somewhat darker than that of the native sand. Following project completion, mechanical tilling of the substrate occurred to ensure that the shear resistance (beach hardness) measured less than 35.2 kg/cm<sup>2</sup>, as recommended for turtle nesting beaches by the U.S. Fish and Wildlife Service and the Florida Department of Environmental Protection.

During the six month interlude between the 2002 and 2003 marine turtle nesting seasons, data from the beach profile indicated that due to natural wave forces the nourished beach exhibited an average decrease in berm width of 4.1 m, the MHWL retreated 6.58 m and the seaward edge of the berm increased in height

an average of 3.1 m (Olsen Associates, Inc., 2003b). Sediment characteristics remained constant but were influenced by natural sorting and redistribution via wind and wave activity. The surface color of the fill material lightened significantly, becoming almost indistinguishable from the native sand (M. McGarry, pers. comm.). Using a soil compaction meter (cone penetrometer, Field Scout Model # SC900), it was concluded that tilling was not required to loosen the substrate (average readings at sample depths did not exceed 35.2 kg/cm<sup>2</sup>) and there were no observed escarpments or other features that indicated a need for mechanical grading or tilling before the 2003 nesting season (Geomar Environmental Consultants, Inc., 2003a).

Since 1989, systematic marine turtle nesting surveys have been conducted on the beach encompassing the nourishment project and throughout the remaining 40.5 km beach. Consequently, a sizeable database of baseline and pre-nourishment data has been established regarding marine turtle nesting and reproduction. It has been determined that this beach provides the nest sites for 25% of the entire western Atlantic loggerhead (*Caretta caretta*) population and 40-45% of the Florida Atlantic green turtle (*Chelonia mydas*) population (Ehrhart et al., 2003). As a result, an adequate assessment of pre- and post-nourishment comparisons to adjacent non-nourished (natural) beaches can allow annual fluctuations and natural patterns to be considered when determining the effects of beach nourishment to loggerheads and green turtles. The physical attributes of

the adjacent non-nourished beaches and that of the nourished beach pre-nourishment (1990-2001) include a 5m to 15m wide relatively sloped berm with general characteristics of a high energy beach within a barrier island ecosystem. The northern reach of the study area has experienced significant growth and development, while the southern end has been established as a National Wildlife Refuge and remains relatively undeveloped (Witherington, 1986; Osegovic, 2001; Weishampel et al., 2003). Prior studies have established that historically this study area has exhibited no significant differences in marine turtle reproductive success or nesting success, although varying amounts of human population and influence exist throughout (Osegovic, 2001; Weishampel et al., 2003). Comparisons of marine turtle nesting activity and reproductive success on the 5 km nourished beach were made with those of turtles nesting on adjacent sections of non-nourished beach (13.5 km north and 22.0 km south of the nourished beach).

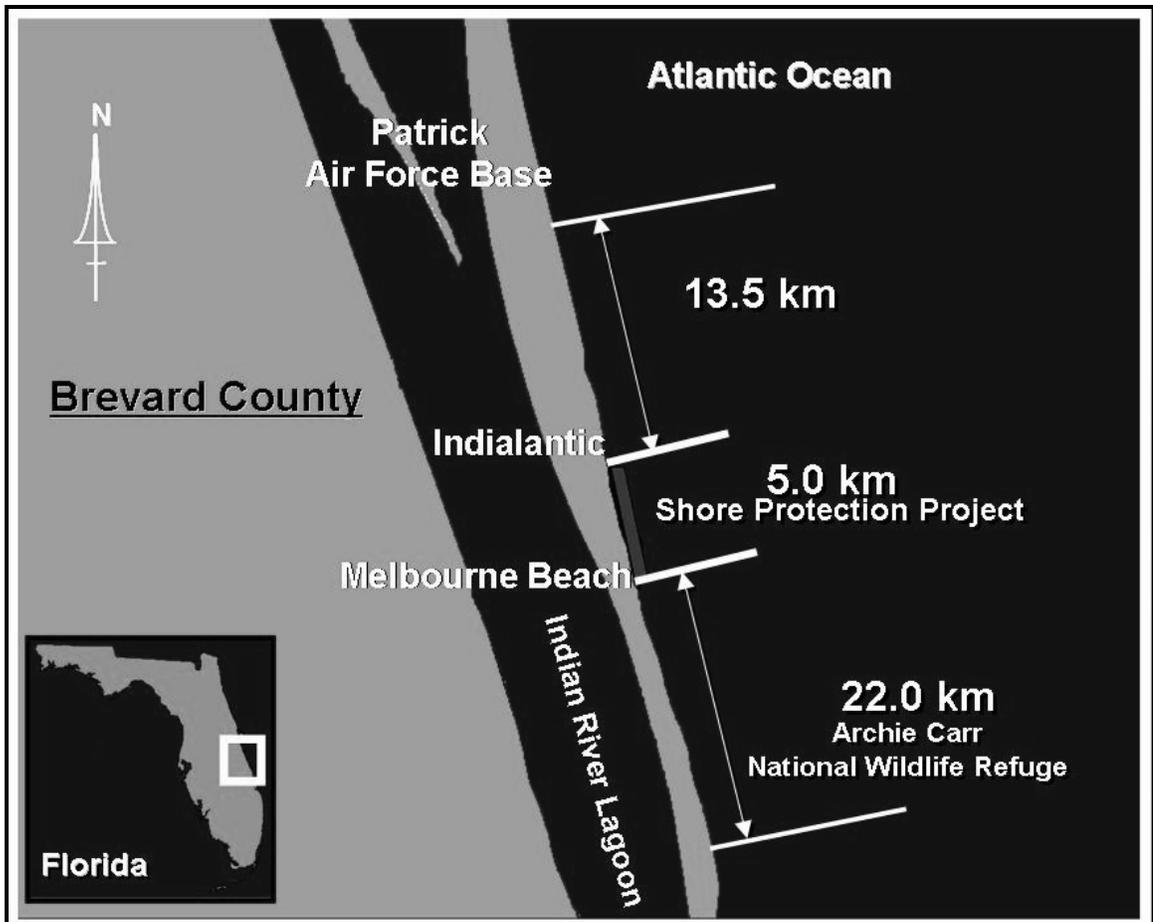


Figure 1. The 40.5 km study area located in Brevard County, Florida. The map indicates the location of the 5 km Brevard County Shore Protection Project and the adjacent sections of non-nourished beach (13.5 km north and 22.0 km south of the nourished beach).

## NESTING ACTIVITY AND PLACEMENT

Evidence of nesting activity was recorded daily from May 1 to August 31 during morning surveys using an all-terrain vehicle. Tracks were differentiated as a nesting or non-nesting emergence based on track patterns and identified to species using species-specific characteristics of the tracks and nests (Pritchard and Mortimer, 1999; Schroeder and Murphy, 1999). Nesting success was calculated as the number of emergences that resulted in nests divided by the total number of emergences. The nourished beach was divided into sections perpendicular to the long axis of the beach and were defined by descriptive differences as:

1. Dune: naturally elevated westward portion including natural vegetation.
2. Foredune: constructed mound at base of dune, may include vegetation.
3. Berm: flat area comprising the greater part of the beach.
4. Gradient: sloping portion seaward of the berm.
5. Scarp: escarpment formed along the seaward edge, due to erosion.

The section category of nourished beach in which a nest was deposited, or at the apex of a non-nesting emergence, was recorded. The apex is defined as the pivot point or area on the beach where a female aborts a nesting attempt and returns to the water without oviposition occurring.

For nests selected to be evaluated for reproductive success (described below) and two arbitrarily chosen non-nesting emergences per day, straight-line measurements were taken from the location of the clutch or the apex of non-nesting emergences eastward to the most recent mean high water line (MHWL) and westward to the upper margin of the berm at the base of the dune. At various locations a seawall or building may have indicated the dune base. The combined measurements of distance to dune base and distance to MHWL were used to calculate the width of beach available to the female upon emergence. For all non-nesting emergences the stage to which nesting activity progressed before abortion of the attempt occurred was categorized as: 1) emergence, no attempt to excavate sand; 2) preliminary body pit, two parallel ridges of sand with no indication of an egg chamber; or 3) an open egg chamber abandoned before oviposition occurred.

#### REPRODUCTIVE SUCCESS

Nests used to evaluate reproductive success were selected and marked the morning following oviposition (Osegovic, 2001). Nest marking methodology, as outlined by Osegovic, included a count of the total number of eggs in each nest. Throughout the incubation period, nests were monitored for disturbances such as raccoon depredation and washing out by high tides or erosion. Raccoon

(*Procyon lotor*) habitat, density and removal efforts vary throughout the study area. To avoid confounding variables in areas with higher depredation rates, marked nests that were destroyed by raccoons have been eliminated from the analysis of reproductive success. Nests that were washed out due to storms or erosion are included in the reproductive success measures as zero percent hatching and emerging success. Each nest was excavated seventy-two hours after the last hatchling track was observed or 65 to 70 days after oviposition. Nest contents were exhumed and evaluated for reproductive success using techniques outlined by Miller (1999) and Osegovic (2001). Three measures of reproductive success were employed to describe aspects of survivorship and productivity: 1) hatching success, defined as the number of empty eggshells (i.e., hatched) calculated as a percentage of the number of eggs in the clutch; 2) emerging success (i.e., the number of hatchlings that reach the surface of the sand), defined as the number of empty eggshells minus the dead and live hatchlings still in the nest, calculated as a percentage of the number of eggs in the clutch; 3) reproductive output, determined by multiplying the total number of nests deposited by the mean emerging success and mean clutch size of sampled nests. Calculation of reproductive output is an estimated number of hatchlings entering the ocean and does not take into consideration post-emergence hatchling mortality.

## POST-EMERGENCE HATCHLINGS

I attempted to quantify the post-emergence disturbances caused by artificial lighting. When evidenced by tracks found during morning surveys, the modal direction of emerging hatchlings was noted. Hatchlings were considered disturbed by artificial lights if the angular direction of travel varied from a “V” formation and were circular in nature, or when the tracks were mostly in a “V” formation but the direction of travel was in a direction away from the ocean (Miller, 1999; Witherington and Martin, 2000). The extent of each incident (per emergence) was determined by counting the number of disturbed hatchling tracks: mild (05-29), moderate (30-69), or severe (70 or more).

## DATA ANALYSIS

Historically, loggerhead nest numbers in Brevard County have been significant but highly variable from year to year, whereas green turtle nesting has followed a pronounced biennial pattern with significant numbers only recorded during even numbered years (i.e. 2000, 2002) (Weishampel et al., 2003). Consequently, the historical comparisons for the individual species were established by the observed pattern in nest production. Data collected during the 2002 and 2003 loggerhead reproductive seasons were analyzed for differences between the

nourished and non-nourished study sites; 1) historical average (1990-2001), 2) one year prior to nourishment (2001), and 3) for two seasons post nourishment (2002 and 2003). Data collected during the 2002 green turtle reproductive season was analyzed for differences between the nourished and non-nourished study sites; 1) historical biennial average (1990-2000) (even years only) and 2) two years prior to nourishment (2000). Differences between species were analyzed using the 2002 data and historical averages recorded during the even years when green turtles nested in significant numbers. Nonparametric statistical tests were used in most analyses due to non-normality of the data. A probability of 0.05 or less was considered significant unless otherwise stated.

## **RESULTS**

### NESTING ACTIVITY AND PLACEMENT

Loggerhead nesting in the nourished areas decreased from 2001 (n = 1828) to 2002 (n = 972) and increased during 2003 (n = 1798), whereas nesting in the non-nourished area decreased from 2001 (n = 17051) to 2002 and 2003 (15014 and 13546 nests, respectively). Nesting success was significantly lower in the nourishment area than in the non-nourished area one season pre-nourishment

and the first and second seasons post-nourishment (Table 1). In both areas, a significant decrease occurred during 2002, relative to 2001 (nourished; Chi-square test = 523.66,  $df = 1$ ,  $p < 0.0001$ ) (non-nourished; Chi-square test = 1134.8,  $df = 1$ ,  $p < 0.0001$ ) (Table 1). However, a 48.4% and 22.3% decrease in the nourished and non-nourished areas, respectively, resulted in the largest historical difference (Figure 2). In 2003, nesting success increased significantly in the nourished (Chi-square test = 334.17,  $df = 1$ ,  $p < 0.0001$ ) and non-nourished areas (Chi-square test = 449.04,  $df = 1$ ,  $p < 0.0001$ ) (42.6% and 15.6%, respectively) (Figure 2).

As expected, 2002 (an even year) was a high green turtle nesting season. Green turtle nesting increased in the non-nourished area from 2000 to 2002 (2661 and 2998 nests, respectively) but decreased in the nourished area (312 and 198 nests, respectively). For the historical mean nesting success rates were not significantly different (Table 2). The even numbered season prior to the nourishment (2000), nesting success rates were significantly higher in the nourishment area compared to the non-nourished areas, whereas during the first season post-nourishment (2002) the nourished area was significantly lower (Table 2). However, nesting success in both areas were significantly lower in 2002 than 2000 (nourished; Chi-square test = 143.23,  $df = 1$ ,  $p < 0.0001$ ) (non-nourished; Chi-square test = 16.829,  $df = 1$ ,  $p < 0.0001$ ), decreasing 7.3% and 54.7% in the non-nourished and nourished areas respectively (Figure 3).

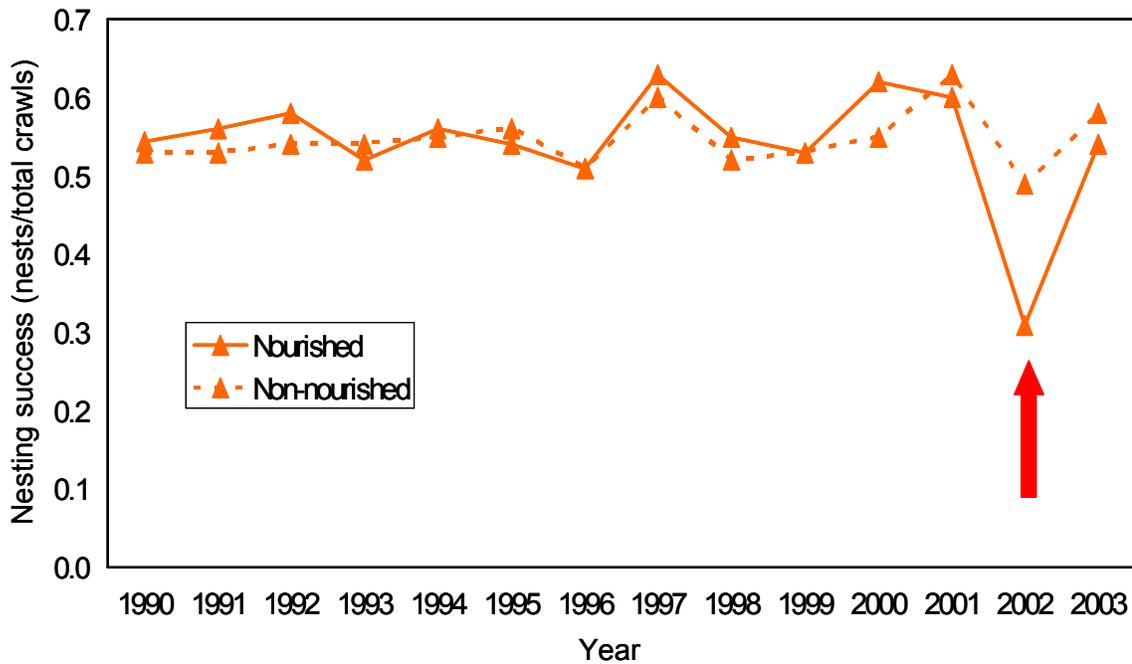


Figure 2. Comparison of loggerhead nesting success between the nourished and non-nourished areas. The arrow indicates the first year immediately following the nourishment project.

Table 1. Loggerhead nesting success prior to and post nourishment on each beach. Values in parentheses are total numbers of nests.

Nourishment status				
Year	Nourished	Non-nourished	t, $\chi^2$	p
12 season mean pre-nourish 1990 - 2001	0.56 $\pm$ 0.01 (22195)	0.55 $\pm$ 0.01 (220571)	1.50	n.s.
season 1 pre-nourish 2001	0.60 (1828)	0.63 (17051)	8.15	0.004
season 1 post-nourish 2002	0.31 (972)	0.49 (15014)	358.66	<0.0001
season 2 post-nourish 2003	0.54 (1798)	0.58 (13546)	23.50	<0.0001

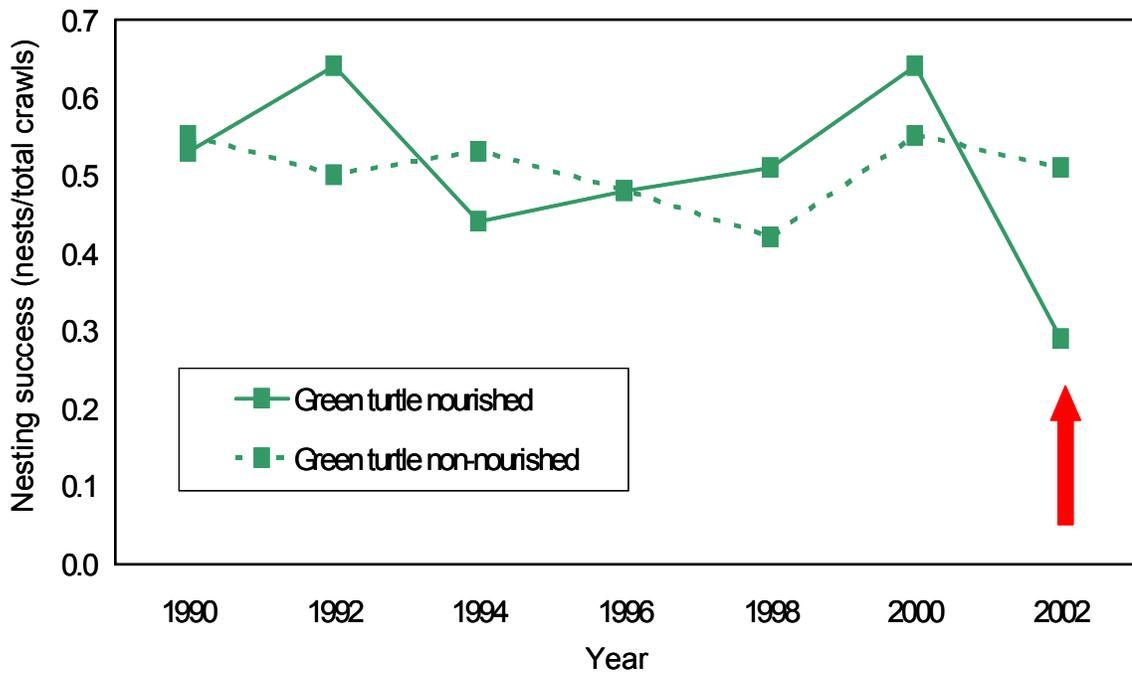


Figure 3. Comparison of green turtle nesting success between the nourished and non-nourished areas measured during (even years only). The arrow indicates the first year immediately following the nourishment project.

Table 2. Green turtle nesting success prior to and post nourishment on each beach. Values in parentheses are total numbers of nests.

Nourishment status Year	Nesting Success		t, $\chi^2$	p
	Nourished	Non-nourished		
6 season mean pre-nourish 1990-2000 (even years)	0.54 $\pm$ 0.03 (734)	0.50 $\pm$ 0.02 (7778)	0.10	n.s.
season 2 pre-nourish 2000	0.64 (312)	0.55 (2661)	13.15	0.0003
season 1 post-nourish 2002	0.29 (198)	0.51 (2998)	124.90	<0.0001

Loggerhead and green turtle nesting success exhibited no significant differences except during 2002 in the non-nourished area (Table 3). From 2000 to 2002, loggerhead and green turtle nesting success decreased approximately 50% and 10% in the nourished and non-nourished areas, respectively (Figure 4).

Of the non-nesting emergences observed after nourishment, more emergences were aborted with no attempt to dig than at any other stage. In 2002, cessation of loggerhead nesting activity resulted in 34 (1.6%) abandoned egg chambers, 403 (18.7%) preliminary body pits, and 1717 (79.7%) emergences with no attempt to dig. Green turtle nesting activity resulted in 16 (3.2%) abandoned egg chambers, 90 (18.1%) preliminary body pits, and 390 (78.6%) emergences with no attempt to dig. Loggerhead non-nesting emergences, during 2003, resulted in 116 (7.5%) abandoned egg chambers, 443 (28.5%) preliminary body pits, and 997 (64.1%) emergences with no digging.

Distributions of nests and apexes of non-nesting emergences in regards to the descriptive section of the nourished beach profile are indicated in Table 4. Green turtles nested on the constructed foredune most often. During 2002, over half of the loggerhead crawls were deposited on the berm. However, in 2003, significant

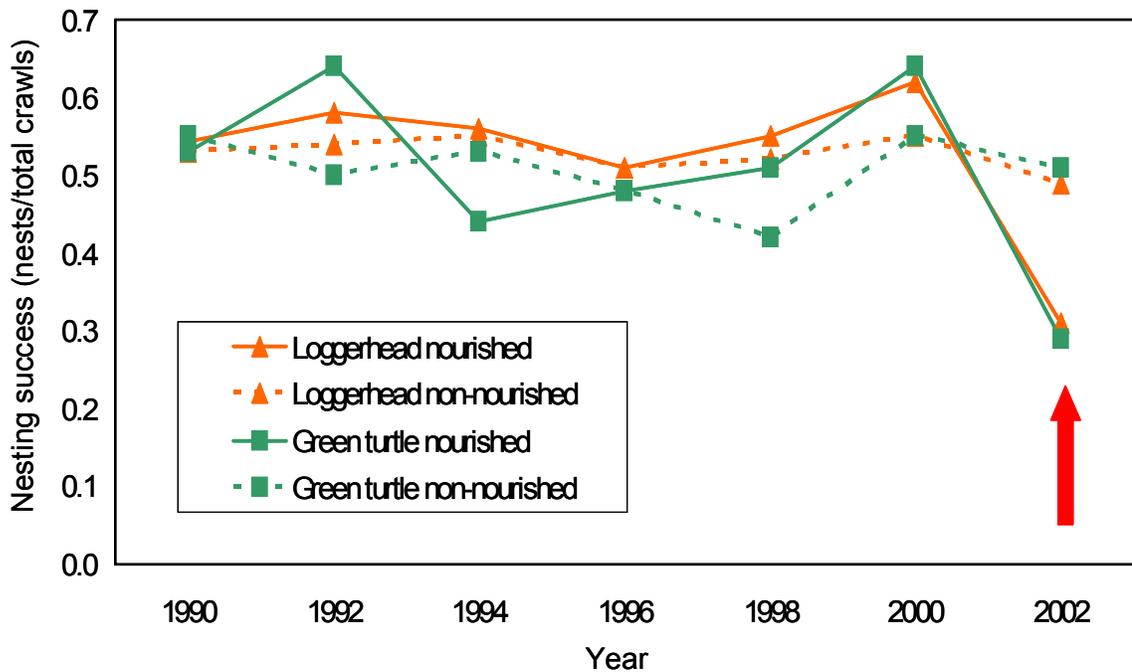


Figure 4. Comparisons of loggerhead and green turtle nesting success between the nourished and non-nourished areas measured during even numbered years only. The arrow indicates the first year immediately following the nourishment project.

Table 3. Loggerhead and green turtle nesting success comparisons prior to and post nourishment on each beach. Values in parentheses are total numbers of nests.

Nourishment status	Nourished				Non-nourished			
	Year	Green turtle	Loggerhead	t, $\chi^2$ p	Green turtle	Loggerhead	t, $\chi^2$ p	
6 season mean pre-nourish 1990-2000 (even years)		0.56 ± 0.03 (734)	0.56 ± 0.02 (11827)	0.81 n.s.	0.50 ± 0.03 (7778)	0.53 ± 0.03 (113628)	1.70 n.s.	
season 2 pre-nourish 2000		0.64 (312)	0.62 (2570)	0.78 n.s.	0.55 (2661)	0.55 (20623)	0.07 n.s.	
season 1 post-nourish 2002		0.29 (198)	0.31 (972)	1.64 n.s.	0.51 (2998)	0.49 (15014)	9.20 0.002	

decreases in the distance from high tide (Kruskal-Wallis Statistic = 59.17,  $p < 0.001$ ) and increases from distance to dune (Kruskal-Wallis Statistic = 87.19,  $p < 0.001$ ) were documented for nesting crawls for loggerheads (Table 5). This changed the distribution of nest placement such that more nests were placed on the gradient in 2003 (Tables 4 and 5).

Correlations among the measured beach width and the straight-line distance from the mean high water line (MHWL) to nests or the apex (point of return) of non-nesting emergences (Table 6), indicate that crawl length was strongly correlated to beach width in the non-nourished area for both loggerheads and green turtles. In the non-nourished area, green turtles crawl somewhat farther from the water than loggerheads, but not with statistical significance. Both species crawled significantly farther from the MHWL in the nourished area than in the non-nourished area before nesting or aborting a nesting attempt. A significant correlation between crawl length and beach width in the nourished area was exhibited by green turtles but did not exist for loggerheads. On the nourished beach green turtles crawled significantly farther than loggerheads (Table 6). For both areas, the crawl lengths of nesting and non-nesting attempts were not significantly different, with the exception of green turtle nests being significantly longer than non-nesting attempts on the nourished beach (Table 6).

Table 4. Distribution of nests and apexes of non-nesting emergences in regards to the nourished beach profile.

Section	Green turtle		Loggerhead			
	2002		2002		2003	
	Nest	Apex	Nest	Apex	Nest	Apex
Scarp	0.0%	0.4%	0.1%	0.3%	0.1%	38.7%
Gradient	0.5%	10.3%	12.1%	8.7%	51.3%	0.1%
Berm	7.0%	61.5%	55.9%	71.4%	40.4%	50.6%
Foredune	91.4%	27.0%	31.5%	18.5%	8.1%	10.2%
Dune	1.1%	0.8%	0.4%	1.0%	0.2%	0.4%
Total	198	496	972	2154	1798	1556

Table 5. Distribution of nests and apexes in regards to the mean measured distances (m) from the dune and high tide on the nourished beach. Values in parentheses are numbers of measurements.

Variable	Green turtle		Loggerhead			
	2002		2002		2003	
	Nest	Apex	Nest	Apex	Nest	Apex
Dune	5.0 ± 1.1 (93)	36.6 ± 1.6 (93)	20.1 ± 1.5 (136)	23.9 ± 1.3 (136)	31.1 ± 1.3 (110)	14.3 ± 1.3 (110)
HT	20.6 ± 1.4 (108)	24.4 ± 1.4 (108)	22.7 ± 1.2 (153)	19.6 ± 1.5 (153)	29.9 ± 1.3 (60)	15.2 ± 1.3 (60)

Table 6. Relationship between the measured beach width and the straight-line distances from the mean high water line (MHWL) to nest sites or the apex of non-nesting emergences. Values in parentheses are numbers of measurements. A Kruskal-Wallis ANOVA (H value 289.0,  $p < 0.0001$ ) indicated significant differences. Dunn's multiple comparisons (right) identify the areas and type of emergence when comparisons differed significantly at  $p \leq 0.05$ . Values for loggerheads represent 2002 and 2003 combined and green turtles represent 2002.

Variable	Rho	p	Mean distance from MHWL (m)	Mean beach width (m)	Significant differences Dunn's comparison
Nourished					
Loggerhead nest	0.08	n.s	19.36 ± 0.97 (246)	44.63	Loggerhead nest: nourished > non-nourished
Loggerhead apex	0.15	0.02	18.58 ± 0.82 (251)	43.87	Loggerhead apex: nourished > non-nourished
Green turtle nest	0.67	<0.0001	36.24 ± 1.43 (107)	41.27	Green turtle nest: nourished > non-nourished
Green turtle apex	0.22	0.03	24.43 ± 1.42 (108)	45.05	Green turtle apex: nourished > non-nourished
Non-nourished					
Loggerhead nest	0.74	<0.0001	9.66 ± 0.34 (232)	15.29	Nourished: Green turtle nest > Green turtle apex Nourished: Green turtle nest > Loggerhead nest
Loggerhead apex	0.62	<0.0001	9.91 ± 0.35 (209)	14.01	Nourished: Green turtle apex > Loggerhead apex
Green turtle nest	0.86	<0.0001	12.69 ± 0.51 (164)	14.90	
Green turtle apex	0.91	<0.0001	9.93 ± 1.25 (17)	11.30	

## REPRODUCTIVE SUCCESS

Loggerhead mean hatching and emerging success between the nourished and non-nourished beaches increased insignificantly each year (2001 - 2003) (Table 7). Hatching success increased in the nourished area relative to the previous year in 2002 and 2003, but not with statistical significance (Table 7). Green turtle reproductive success rates did not differ significantly between beaches in 2000 or in 2002 (Table 8). A significant increase from 2000 to 2002 occurred for both areas, with the exception of emerging success in the nourished area. Emerging success rates in the nourished area increased (but not significantly) from 2000 to 2002 (Table 8). During 2002, loggerhead and green turtle hatching and emerging success did not differ significantly between areas or between species in the same area (Table 9).

Hatching success (HS), excluding washed out nests, was significantly higher in the nourished area than the non-nourished area for loggerheads in 2002 and 2003, but green turtle HS in 2002 was not significantly different in either of the areas (Tables 10 and 11). During 2002, comparisons between loggerhead and green turtle hatching success did not differ significantly between species in the same area (Table 11).

Table 7. Loggerhead turtle mean hatching and emerging success during years prior to and post nourishment compared during the same years and compared between years for each beach. A significant H value indicates that the values were different (Kruskal-Wallis ANOVA). Dunn's multiple comparisons (right) identify the years or areas when comparisons differed significantly. Numbers in parentheses are the numbers of nests.

Category	Year	Nourishment status	Nourished	Non-nourished	H value	p	Significant differences Dunn's comparison
Hatching success	2001	season 1 pre-nourish	46.7 ± 8.8% (18)	47.6 ± 3.2% (143)	32.1	ns	
	2002	season 1 post-nourish	59.9 ± 3.2% (152)	56.8 ± 2.8% (177)			
	2003	season 2 post-nourish	69.2 ± 3.3% (106)	67.2 ± 2.2% (186)			
Category	Year	Nourishment status	Nourished	Non-nourished	H value	p	Significant differences Dunn's comparison
Emerging success	2001	season 1 pre-nourish	46.4 ± 8.8% (18)	45.5 ± 3.2% (143)	33.1	ns	
	2002	season 1 post-nourish	58.9 ± 3.3% (151)	55.2 ± 2.8% (177)			
	2003	season 2 post-nourish	66.9 ± 3.4% (106)	65.9 ± 2.2% (186)			

Table 8. Green turtle mean hatching and emerging success during years prior to and post nourishment compared during the same years and between years for each beach. A significant H value indicates that the values were different (Kruskal-Wallis ANOVA). Dunn's multiple comparisons (right) identify the years or areas when comparisons differed significantly. Numbers in parentheses are the numbers of nests.

Category	Year	Nourishment status	Nourished	Non-nourished	H value	p	Significant differences Dunn's comparison
Hatching success	2000	season 2 pre-nourish	51.3 ± 5.2% (7)	46.8 ± 5.3% (41)	25.9	<0.0001	Non-nourished: 2000<2002 Nourished: 2000<2002
	2002	season 1 post-nourish	73.4 ± 2.0% (136)	64.0 ± 2.5% (141)			
Category	Year	Nourishment status	Nourished	Non-nourished	H value	p	Significant differences Dunn's comparison
Emerging success	2000	season 2 pre-nourish	50.1 ± 5.1% (7)	46.6 ± 5.2% (41)	22.4	<0.0001	Non-nourished: 2000<2002
	2002	season 1 post-nourish	71.0 ± 2.1% (136)	62.9 ± 2.5% (141)			

Table 9. Loggerhead and green turtle mean hatching and emerging success during the first season post-nourishment compared during the same year and between species. Dunn's multiple comparisons (right) identify when comparisons differed significantly. Numbers in parentheses are the numbers of nests.

Category	Nourished	Non-nourished	H value	p	Significant differences Dunn's comparison
Hatching success					
Loggerhead	59.9 ± 3.2% (152)	56.8 ± 2.8% (177)	7.5	ns	No differences
Green turtle	73.4 ± 2.0% (136)	64.0 ± 2.5% (141)			
Emerging success					
Loggerhead	58.9 ± 3.3% (151)	55.2 ± 2.8% (177)	7.0	ns	
Green turtle	71.0 ± 2.1% (136)	62.9 ± 2.5% (141)			

Estimated loggerhead reproductive output for the non-nourished area increased 23.0% from 2001 to 2003, (8.0% and 16.3%, 2002 and 2003, respectively) (Figure 5). The nourished area produced 52.2% fewer hatchlings in 2002 than in 2001 and 44.1% more hatchlings in 2003 than in 2002 for a 14.9% increase from 2001 to 2003 (Figure 5). Estimated green turtle reproductive output for the non-nourished area increased 48.1% in 2002 and in the nourished area it decreased 0.8% (Figure 6).

#### POST-EMERGENCE HATCHLINGS

A significant increase in disorientation frequency was recorded for each season post-nourishment (Figure 7). Disorientations during 2002 ( $n = 24$ ) were significantly higher than in 2001 ( $n = 4$ ) (Chi square statistic = 27.270,  $p < 0.0001$ ) and in 2003 incidents ( $n = 158$ ) were significantly more numerous than in 2002 (Chi square statistic = 38.347,  $p < 0.0001$ ). The mean number of disorientations in the years from 1995 to 2001 (pre-nourishment) was 1.7 with a maximum of 4 observed in one year. In the non-nourished area, one clutch was disoriented in 2002 and three during 2003. None of the observed disoriented hatchlings were green turtles. The extent of each incident (per emergence) is listed in Table 12.

Table 10. Loggerhead mean hatching success excluding washed out nests during years post nourishment compared to those on the non-nourished beach during the same years and compared between years for each beach. A significant H value indicates that the values were different (Kruskal-Wallis ANOVA). Dunn's multiple comparisons (right) identify the years or areas when comparisons differed significantly. Numbers in parentheses are the numbers of nests.

	2002		2003		H value	p	Significant differences in hatching success Dunn's comparison
	Nourished	Non-nourished	Nourished	Non-nourished			
Washouts	27	27	14	9	17.4	0.0006	2002: Nourished > Non-nourished
Percent marked nests washed out	17.8%	15.3%	13.2%	4.8%			2003: Nourished > Non-nourished
Hatching success	73.4 ± 2.8%	67.0 ± 2.5%	79.7 ± 2.4%	70.7 ± 2.0%			
	(124)	(150)	(92)	(177)			

Table 11. Loggerhead and green turtle mean hatching success excluding washed out nests during the first season post-nourishment compared to those on the non-nourished beach during the same year and compared between species. A significant H value indicates that the values were different (Kruskal-Wallis ANOVA). Dunn's multiple comparisons (right) identify when comparisons differed significantly. Numbers in parentheses are the numbers of nests.

	Loggerhead		Green turtle		H Value	p	Significant differences in hatching success Dunn's comparison
	Nourished	Non-nourished	Nourished	Non-nourished			
Washouts	27	27	7	6	15.3	0.0016	Loggerhead: Nourished > Non-nourished
Percent marked nests washed out	17.8%	15.3%	5.1%	4.3%			
Hatching success	73.4 ± 2.8%	67.0 ± 2.5%	77.4 ± 1.5%	66.9 ± 2.4%			
	(124)	(150)	(129)	(135)			

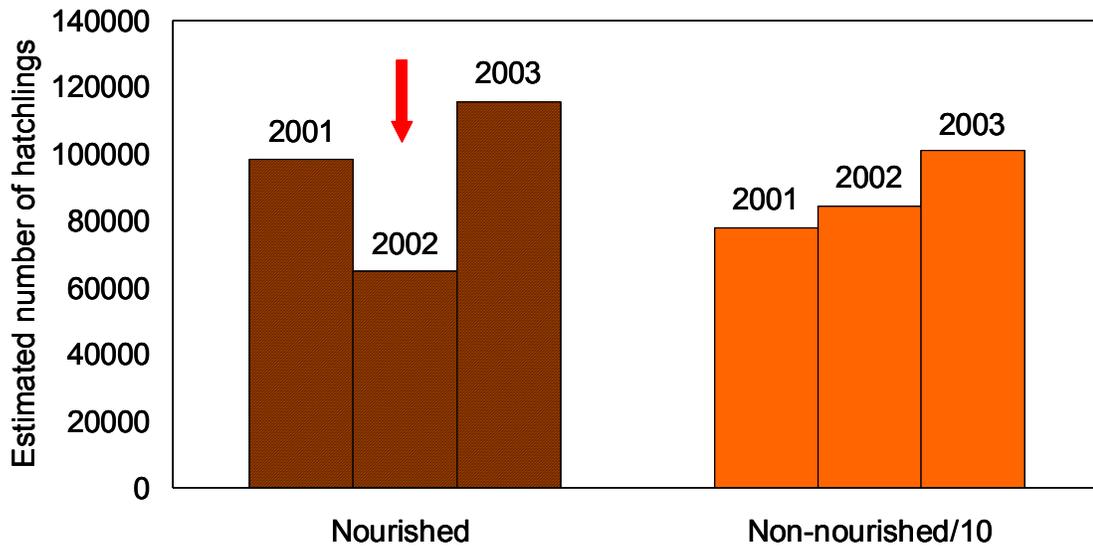


Figure 5. Estimated loggerhead reproductive output for each beach. Note that the numbers for the non-nourished area are divided by 10 due to study site size differences. The arrow indicates the first year following the nourishment project.

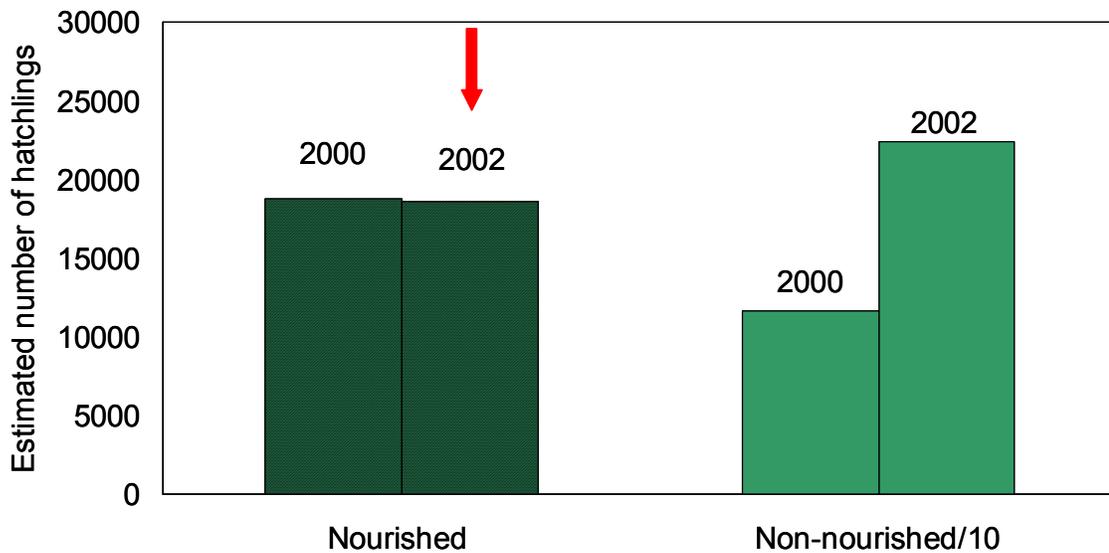


Figure 6. Estimated green turtle reproductive output for each beach. Note that the numbers for the non-nourished area are divided by 10 due to study site size differences. The arrow indicates the first year following the nourishment project.

Table 12. Extent of each observed loggerhead hatchling disorientation. Categories are defined as: mild (05 - 29 hatchlings), moderate (30 - 69 hatchlings), or severe (70 or more hatchlings). Values in parentheses indicate numbers of disorientations.

Year	Nourishment status	Mild	Moderate	Severe	Total
2002	season 1 post-nourishment total season nests = 972	33.3% (8)	41.7% (10)	25.0% (6)	24
2003	season 2 post-nourishment total season nests = 1785	8.9% (14)	23.4% (37)	67.7% (107)	158

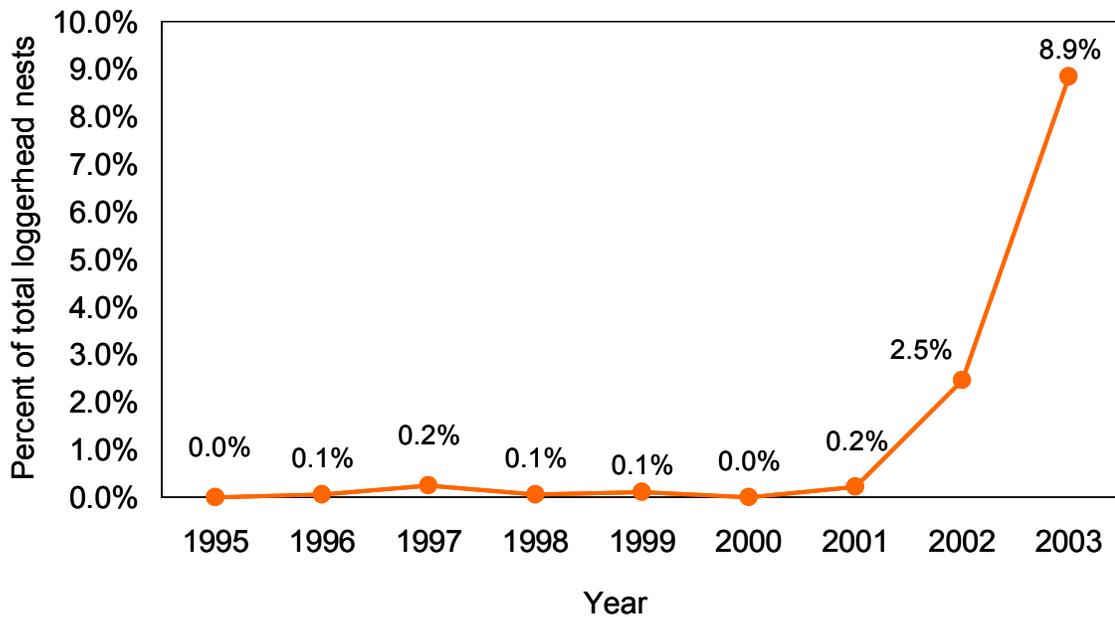


Figure 7. Percentage of loggerhead nests in which hatchling disorientations were observed for the nourished area 1995 to 2003. The first season post-nourishment is 2002.

## DISCUSSION

### NESTING ACTIVITY AND PLACEMENT

I found, at one season post-nourishment, negative effects on nesting success and nest densities for both loggerheads and established the same relationships with green turtles. Physical attributes of the fill sand, which did not facilitate acute scarp formation or severe compaction, did not physically impede turtles in their attempts to nest. Instead, the decrease in nesting success was attributed to an absence of abiotic and or biotic factors that cue nesting behavior. The increase in loggerhead nesting success rates during the second season post-nourishment was attributed to the equilibration process of the seaward crest of the berm.

Many studies have been conducted that discern the effects of beach nourishment upon loggerhead turtles (Fletemeyer, 1984; Raymond, 1984; Nelson and Dickerson, 1989; Ryder, 1993; Bagley et al., 1994; Crain et al., 1995; Milton et al., 1997; Steinitz et al., 1998; Trindell et al., 1998; Davis et al., 1999; Ecological Associates, Inc., 1999; Herren, 1999; Rumbold et al., 2001). Most of these studies concluded that nesting success, and therefore nest density, decreases

during the year following nourishment as a result of escarpments obstructing beach accessibility, altered beach profiles, and increased compaction which impedes proper egg chamber construction.

Low loggerhead nest production in the nourished area was partly the result of annual fluctuations in nest density, as fewer nests were produced in the non-nourished area and statewide. However, low green turtle nest production in the nourished area appears to be a result of the nourishment, as marked growth continued (as expected) in the non-nourished area and was similar to that observed statewide (Florida Fish and Wildlife Research Institute, Index Nesting Beach Survey database). To show how females respond to the altered profile and substrate, it is necessary to compare the efforts (nesting success) of females in their attempts to nest.

Historically (1990-2001), nesting success for the 40.5 km beach has been roughly 0.50, with 50% of all emergences resulting in nests (Weishampel et al., 2003). Low nesting success rates for loggerheads and green turtles (0.31 and 0.29, respectively, this study) in the nourished area one season post-nourishment indicate that females approached and attempted to nest on the nourished beach but were unsuccessful in proportionately more attempts than in previous years on the same beach or in the non-nourished areas under the same annual conditions.

A female's pre-emergent assessment of beach suitability was not within the scope of this study. However, the decrease in nesting success indicates that females were making the offshore approach through an altered surf zone and were subsequently aborting nesting attempts after emerging onto the beach. This would imply that, of the number of females attempting to nest, fewer were receiving the appropriate cue(s) that initiate a nesting response. As a result of low green turtle nest production during 2003, conclusions concerning long-term nesting success rates for green turtles (two to three nesting seasons post-nourishment) cannot be made at this time. The return of loggerhead nesting success to equivalent rates similar to those on the adjacent non-nourished beach and historical rates two seasons post-nourishment was observed during this study (Figure 2).

The reason why nesting success is reduced during the first year post-nourishment for loggerheads has been attributed to escarpments and sediment compaction (Herren, 1999). Sediment compaction meters (cone penetrometers) have been used in previous studies to determine if compaction hindered a turtle's ability to dig. Because of instrument error and given that turtles do not dig vertically in the same fashion as a penetrometer moves through the sediment layers, some have concluded that penetrometers are not appropriate for assessing turtle nesting limitations (Davis et al., 1997). If shear resistance

("compaction") of the nourished substrate prevented females from digging in the sand and was a major factor in the decrease in nesting success, a large portion of abandoned egg chambers or shallow nests with overflowing eggs would be expected (Raymond, 1984). The numbers of abandoned egg chambers recorded for loggerheads and green turtles in the nourished area were minimal (166 out of 4206 non-nesting emergences) and no nests with overflowing eggs were observed. As a result, I conclude that the relatively friable nature of the substrate offered little or no impediment to sea turtles attempting to excavate an egg chamber. An additional effect related to increased sediment compaction is an increase in the prevalence of scarping. The large particle size of the nourishment substrate did not facilitate excessive scarp formation and so did not prevent turtles from accessing the full width of the beach as reported in Herren (1999). Severe sediment compaction and acute escarpments did not impede or thwart turtles in attempts to access the beach and nest. Instead, more of the nesting attempts were abandoned on the berm with no effort to dig or begin a body pit. The increase in non-nesting attempts (with no digging) and the absence of scarp formations may indicate an absence of abiotic factors that cue the female to initiate nesting. Investigating the proximate cues that a turtle perceives as it ascends the beach would provide an understanding of why nourishment substrates are not well received by turtles.

Marine turtles in the genera *Caretta* and *Chelonia* have a fixed nesting behavior

pattern that includes often pressing their heads into the sand as they ascend the beach. This behavior is perhaps to monitor microhabitat characteristics of potential nest sites (Wood and Bjorndal, 2000). The environmental cues that are potentially evaluated by the female are moisture, temperature, salinity, and slope. However, the exact cues that a turtle uses when selecting a final nesting site are not well understood. Rather than one cue signaling the commencement of nesting behavior, multiple environmental cues within the microhabitat may initiate nesting behavior, with each factor reached in a series or integrated as specific patterns of associations (Wood and Bjorndal, 2000).

Turtles nest on a variety of beach types, and the reasons females nest on some beaches and not others are not necessarily obvious (Mortimer, 1995). The feature that makes one beach favorable may not be a factor at other beaches (Salmon et al., 1995). The literature regarding inter and intraspecific differences in the finer details of nesting patterns vary almost as much in reports on the same species as those found between species (Hendrickson, 1995). Green turtles nest in sands that vary in terms of color, mineral composition and texture and show a wide tolerance for variations in grain size distribution, water content, pH, organic content, and calcium carbonate content (Stancyk and Ross, 1978; Mortimer, 1990). Wood and Bjorndal (2000) tested for the environmental factors that appeared to have the greatest influence on loggerhead nest placement at Melbourne Beach (non-nourished area for the current study). Temperature,

salinity and moisture were determined to not be reliable cues for nest site selection because they are highly variable factors that change with rainfall and water table fluctuations. In addition, the concentrated salt solutions secreted by the lachrymal glands (Lutz, 1997) probably would interfere with the ability of turtles to monitor sand salinity. Slope, which usually indicates an area of the beach with higher elevation and thus higher probability of nest survival, had the greatest observable influence on nest placement. Along this same beach, Weishampel et al. (2003) determined that the nesting activity for loggerheads and green turtles is significantly correlated throughout the study area and that, although correlation does not imply causation, both species appear to be responding to similar mechanisms that initiate nesting. The analogous decrease in nesting success during the first year for loggerheads and green turtles, in response to the nourished beach, and the similarities in the stage at which non-nesting emergences were aborted, would suggest that both species had similar negative neurological responses to the presence or absence of the same environmental cue(s) that initiate a nesting response. Further examination of the modifications that occurred to the nourished beach during the interlude between the first and second seasons post-nourishment that possibly explain the increase in loggerhead nesting success during the second year (2003), suggests that the recovery of green turtle nesting success rates may not occur as quickly. The correlation in nesting success between the two species on the natural beach could be a result of a correlation of different factors that initiate nesting for the

two species.

Typically, in the first season post nourishment, loggerhead nesting success is significantly below average, followed by a return to near average levels during the second or third seasons. During a seven-year study, Steinitz et al. (1998) found that nesting success on nourished and natural beaches become more comparable when the physical characteristics of the beaches become similar. In 2001, at Juno Beach, beach nourishment did not significantly decrease loggerhead nesting the first season post nourishment (Palm Beach County Department of Environmental Resources Management, 2001). The report attributed the results to a relatively early project completion date (late January/early February) followed by sufficient wave activity that shaped the beach to the equilibrium profile and significantly reworked the sediments along the seaward portion of the dry beach prior to the nesting season. A profile at equilibrium as used by coastal engineers is defined as the natural form that the beach would take for a given volume of sand of a particular grain size under the prevailing wave environment (Committee on Beach Nourishment and Protection, 1995). On average it takes 6-8 months for a profile to equilibrate, depending on wave conditions.

The completion date of the nourishment project in this study was April 24; storm and wave activity had not equilibrated the new profile of the nourished beach

before nesting began in 2002, but had done so prior to the 2003 season. During 2002, the nourished beach was characterized as extensive and relatively level or flat (zero ft constructed slope) unlike the sloping nearby beaches. The cross sectional profile remained the same during 2003 with the exception of the differences in the equilibration along the seaward portion of the dry beach (described previously in the study sites section). The change in distribution of loggerhead nests (Table 4 and 5) from the berm to the gradient, with a corresponding significant decrease in crawl distance during 2003, supports the hypothesis that the equilibrated seaward face of the beach (the gradient) became more attractive to loggerheads as they searched for a nesting site. This timing suggests that the unequilibrated beach profile, which turtles traversed when selecting a nest site, was a major contributor to the decrease in nesting success during 2002. Thus, the corresponding increase in loggerhead nesting success during 2003 is attributed to the new equilibrium profile. The inclination for loggerhead turtles to deposit nests just above or on the gradient of the nourished profile predisposes them to respond to the equilibration process, whereas green turtles use the constructed foredune feature most often when nesting and so are less inclined to respond to the equilibration process. For these reasons, green turtles may very well experience a decline in nesting success three to four seasons post-nourishment or until the niche they use becomes more suitable.

Species-specific differences exist in parameters such as habitat preferences for

nest placement within a single beach (Meylan and Meylan, 1999). On the non-nourished beach, loggerhead turtles tend to nest near the vegetation at or in front of the dune, while green turtles nest higher on the beach than loggerheads, often in the highly vegetated areas at or behind the dune (Witherington, 1986; Johnson, 1994; Wood and Bjorndal, 2000). When additional habitat was made available (wider beach) by the nourishment project, the significant correlation between beach width and distance of nests from mean high water line no longer existed for loggerhead turtles (Table 6). Loggerhead turtles failed to vary crawl distance to traverse the entire length of the berm to nest at or in front of the dune. Instead, they crawled a distance (23.9 m) from the sea, which is nearly equal to the mean distance reported for loggerheads nesting on natural beaches elsewhere (Wood and Bjorndal, 2000; Hays and Speakman, 1993). However, in the current study, nests were not within the reported average of 2.2 m from the dune as found by Wood and Bjorndal (2000). This difference indicates that loggerheads move somewhat further inland when wider beaches are available, but do not place nests in the same location as on nearby naturally narrow beaches. The tendency to nest near the dune was replaced with a tendency to nest on the seaward crest of the berm or the gradient and so what appeared to have been a consistent nesting preference was changed for loggerheads when the nourishment project offered a wider beach. Loggerhead nest distributions on the seaward crest of the berm (the gradient) and further from the MHWL and the dune have been observed on other nourished beaches (Ernest et al., 1998;

locco, 1998; Herren, 1999; Ecological Associates, Inc., 1999; Ehrhart and Roberts, 2001). As previously reported for loggerheads nesting on natural beaches on the islands of Cephalonia, Greece (Hays and Speakman, 1993), nest placement may have been restricted by vegetation and beach width. Crawl distances of nesting and non-nesting emergences from the mean high tide line did not differ significantly. Therefore, it is unlikely that turtles used cues upon first emergence nor did they explore more of the beach in search of cues that would initiate nesting.

The wider nourished beach did not alter green turtle preferential nest placement; females increased crawl lengths inland, traversing the entire nourished profile (mean beach width = 41.3 m) to nest on the constructed foredune and dune (Table 6). The increase in the distance that green turtles nested from the sea when the dune was further from the water (nourished) suggests that the variables associated with the dune or vegetation may be necessary cues that initiate nesting. The non-nesting crawl lengths were significantly shorter than the nesting attempts in the nourished area but not significantly different on the narrow non-nourished beach. This difference indicates a relatively early termination of a nesting attempt before reaching the dune on the nourished beach. Turtles that crawled farther and reached the foredune area nested more often than those that did not crawl as far. This result supports the idea that variables associated with the presence of a dune feature initiated nesting on the nourished beach.

Both species of turtles crawled significantly farther and aborted more nesting attempts on the nourished beach. This increased movement could increase the energy expenditure of the nesting females and the energetic expenditure and predation risks of emerging hatchlings from these nests (Horrocks and Scott, 1991). Differences in preferred nesting locations would imply that green turtles would be affected by increased energy expenditures more so than loggerheads, because green turtles traverse the entire nourished berm. Selection of a nest site is an adaptive trade-off between the cost of searching for a site and the reproductive benefits of selecting a site suitable for successful incubation (Wood and Bjorndal, 2000). The evolution of an ability of females to select or be more attracted to beaches at which their eggs would have the best chance of survival has not been demonstrated; in fact, turtles sometimes select substrates that produce zero hatching success and contain sands that are less optimal for nest survival (Mortimer, 1990).

#### REPRODUCTIVE SUCCESS

Sediment characteristics may not play an important role in nest site selection but do play an integral role in reproductive success and have profound effects on clutches with respect to embryological development and survival (Bustard, 1972;

McGehee, 1979; Packard and Packard, 1988). Many physical characteristics act independently to influence the success of eggs, but the interactions between several physical factors ultimately determine how substrates affect nest fate (Ackerman, 1996). Nourishment projects can affect the development of eggs by altering beach characteristics such as sand compaction, nutrient availability and the gaseous, hydric and thermal environments (Crain et al., 1995). Nourished beaches have had positive effects (Broadwell, 1991; Ehrhart and Holloway-Adkins, 2000; Ehrhart and Roberts, 2001), negative effects (Ehrhart, 1995; Ecological Associates, Inc., 1998), or no apparent effect (Raymond, 1984; Nelson et al., 1987; Broadwell, 1991; Ryder, 1993; Steinitz et al., 1998; Herren, 1999) on the hatching success of marine turtle eggs. Differences in these findings are related to the differences in the physical attributes of each project, the extent of erosion on the pre-existing beach, and application technique. Those with negative results reported that differences were difficult to explain or hampered by low sample sizes (Ehrhart, 1995; Ecological Associates, Inc., 1998).

As found in this study and in a review of beach nourishment projects, loggerheads preferentially nest on the part of the beach where the equilibration process takes place (Ecological Associates, Inc., 1999). It is critical that an assessment of hatch success include 0% for all washed out nests to give a more conclusive evaluation of the effects on reproductive success. Previous studies

that include an evaluation of reproductive success either do not clearly state how washed out nests were treated or if they were or were not included in the analysis. These differences could be a factor in the discrepancies found throughout the literature concerning the effects of beach nourishment in regards to reproductive success. A calculation of hatching success that excludes washed out nests due to erosion or storms is more indicative of the suitability of the substrate to properly incubate eggs (Witherington, 1986). This calculation would also provide a generalized baseline for comparison to other projects that eliminated those nests from consideration.

The nourished beach did not significantly affect reproductive success as measured by hatching and emerging success for loggerheads or green turtles (Tables 7 and 8). Emerging success rates nearly equal to the hatching success rates and not significantly different from those in the non-nourished area indicate that hatchlings that emerged from eggs did not encounter any difficulties when trying to extricate themselves from the nests in the nourished substrate. These data, which include 0% for all washed out nests, indicate that the nourishment project provided habitat for loggerhead and green turtle reproduction similar to that offered by the non-nourished area. However, when washed out nests were excluded from the analysis, the nourished area produced loggerhead hatching success rates that were significantly higher than the non-nourished area. This higher rate suggests that the substrate was more conducive to the proper

development of loggerhead eggs but that washed out nests along the equilibrated face of the berm reduced the calculated success rate for loggerhead nests (Table 10). The equilibration process of the nourished substrate that contributed to the loss of loggerhead nests did not affect green turtles as severely because the majority of green turtle nests were placed on the foredune. Green turtle nest placement close to the dune is a benefit (Table 11).

Reproductive output or the total number of hatchlings produced, takes into account both nesting and reproductive success. This estimate can be used to determine whether a net benefit or cost to nesting marine turtles was experienced as a result of the nourishment project. Both loggerheads and green turtles experienced a net cost during 2002, followed by a net benefit for loggerheads during 2003 (Figures 7 and 8). The nourishment project reduced the reproductive output regardless of unaffected reproductive success rates. These results indicate that the decrease in reproductive output was due to the significantly lower nesting success, which consequently lowered nesting densities. The second season post-nourishment loggerhead nesting success increased, which resulted in a corresponding increase in reproductive output. These estimates, which include total nest numbers, are influenced by yearly fluctuations in the numbers of females capable of reproducing. Therefore, the observed decreases in reproductive output for loggerheads are exacerbated because of a statewide reduction in loggerhead nesting. In contrast, the

decrease in green turtle reproductive output for the nourished area is lessened due to the increase in nesting green turtles observed statewide. However, these estimates give insight to the consequences of the effects of decreased nesting success beyond that of increased energy expenditure.

#### POST-EMERGENCE HATCHLINGS

Loggerhead hatchling disorientations increased significantly post-nourishment, while no green turtle disorientations were observed. Green turtle hatchling disorientations may have been more logistically difficult to record due to the close proximity of nests to the foredune on the expansive profile that was traversed during morning surveys. It is possible that tracks of disoriented green turtle hatchlings were less conspicuous because they were likely close to and traveled within the vegetation. On the other hand, loggerhead hatchling tracks were more evident because nests were deposited close to the water and hatchlings traversed most of the berm when disoriented towards landward light sources.

A clear cause and effect relationship can be offered as an explanation to the increase in hatchling disorientations observed in the nourished area. The new profile of the beach created by the nourishment project elevated and vastly expanded the beach. An increase in elevation combined with an easterly

expansion allowed light sources not previously visible to be seen by hatchlings. Pre and post nourishment night-time lighting surveys conducted in February of 2002, prior to the nourishment project, and in April 2002, after project completion, indicated that potential lighting problems increased by nearly 3 times (Brock, unpublished data). These lighting surveys were conducted along the same area that supports a majority of the loggerhead nesting. Regardless of greater nesting density in the non-nourished areas, only four disorientation incidents were recorded during 2002 and 2003. The increase in events reported in the nourished area for 2003 relative to those in 2002 is partly the result of an increase in nesting; however, the percentage of total nests disoriented (Figure 7) indicates an increase above that caused by an increase in nest density. Part of this increase is possibly due to an increase in numbers of lights (although few additional buildings were erected) or to surveyor biases. It is believed that during 2002 some disorientations went unobserved during surveys and that only the most conspicuous cases were reported. As more attention was brought to the occurrence of disorientations and as surveyors became better trained at distinguishing multiple disorientations in close proximity, more events were reported. For these reasons, 2003 better represents the effect of beach nourishment to post-emergence hatchlings, as the numbers reported for 2002 are likely an under representation of the actual number of disorientations. The conclusions based on this study remain valid because biases were more likely to fail to report disorientations than to falsely report events.

Hatchling marine turtles rely almost exclusively on vision to orient to the sea and often become disoriented by artificial beachfront lighting (Witherington and Martin, 2000). In the area of beach nourished during 2002, numerous hatchling disorientations are now being observed where previously few had been recorded. The impacts of beach nourishment on marine turtle hatchling disorientation behavior have not been well studied but have been documented on other extensively nourished beaches (Roberts and Ehrhart, 2001; Rusenko et al., 2003; Geomar Environmental Consultants, Inc., 2002). These studies attributed the increases to the elevation of the beach, which increased artificial light exposure to the beach, coupled with insufficient dune vegetation coverage. Due to the obvious association between beach nourishment and disorientations, aggressive nourishment projects necessitate equally aggressive measures to prevent disorientations. Lighting surveys to include pre and post nourishment surveys should be reiterated throughout the nesting season to identify and correct problematic lights. It is imperative to ensure that the lights on the newly nourished beach are within specifications of state and county lighting ordinances implemented to protect marine turtles.

#### COMMENTS ON PROJECT DESIGN

While conceptualizing nourishment as a single entity from individual projects is not ideal, conceptualizing the many facets associated with a successful project is necessary for appropriate assessment (Crain et al., 1995). The difficulty involved in conducting controlled field and laboratory experiments that would determine the precise mechanisms of nesting and reproduction that are affected by beach nourishment requires that we examine individual projects. Those with management responsibilities and coastal engineers should then extrapolate pertinent information when designing and planning future projects.

Comparative data from this study established that a nourishment project, one season post-nourishment, had statistically similar negative effects on loggerhead and green turtle nesting success and no significant differences in reproductive success (rates including wash outs) when compared to the non-nourished area or between species. However, similarities between loggerhead and green turtle nesting success and reproductive success (this study) should not suggest that management policies focusing on beach nourishment practices for one species may be effective for both. The differences in preferential nest placement and the tendency of loggerhead nests to be affected more so by erosion and washed out during the equilibration process should be considered.

The 2002 Brevard County nourishment project implemented all facets of successful nourishment projects in regards to marine turtles known to date (refer

to Geomar Environmental Consultants, Inc., 2003b). These variables include high quality sands (not facilitating escarpments or compaction) and application timing and techniques. The 2002 project incorporated the additional design component of a constructed foredune. This foredune offered a 2.5 m increase in elevation along the landward edge of the berm. While loggerheads did not encounter this feature at the current beach width, nesting green turtles (91.4%) utilized the foredune more than any other section of the beach. This occurrence may have been due to variables associated with or near to the foredune or the elevation of the foredune. Further investigation is warranted.

One of the first and most frequently cited systematic studies designed to test for the effects of beach nourishment to loggerhead turtles was initiated over twenty years earlier within the boundaries of this project. Both studies demonstrated no significant effects to hatching or emerging success regardless of the differences in fill materials between the two projects. Raymond (1984) reported a significant decrease in loggerhead nesting success rates (0.28) one season post-nourishment, followed by an increase the second season post-nourishment (0.46). Twenty-one years later, this study found loggerhead nesting success rates of 0.31 and 0.54 (one and two seasons post-nourishment, respectively). The nourishment project in Raymond's study was completed in February and reportedly experienced a "reworking" of the foreshore prior to the nesting season; however, the substrate used was so compact during the first season post-

nourishment (1981) that it hindered the digging process of females. This compaction was “weathered” and the compact substrate was eroded during the interlude between seasons due to extreme high tides and rough surf associated with two extratropical storms and therefore offered no impediments during the second season. Efforts to use sand with physical attributes similar to that of the native beach and the use of substrate tilling alleviate escarpments and compaction, consequently eliminating the causes of the negative impacts of early beach restoration projects. However, after over twenty years of marine turtle monitoring on the effects of various beach nourishment, low nesting success remains the biggest impact. Nourishment projects as designed and implemented during this study no longer offer physical impediments to nesting turtles but rather cause a negative behavioral response in both loggerheads and green turtles.

The preference of steeply sloped beaches for loggerheads nesting on the Atlantic coast and the return of nesting success rates to more typical rates after the equilibration process implies that the initial beach profile is the greatest cause for the observed decrease in nesting success. If observations concerning the equilibration process and the seaward slope of the profile hold true, future studies should focus on the behavioral mechanisms of nest site selection. Results from the first known beach nourishment project in Florida to purposely slope the berm seaward at a specified grade to improve marine turtle nesting

success, indicate that a 1:67 seaward slope of the berm significantly reduced impacts to marine turtle nesting success the first season post-nourishment (Brock, unpublished data). Efforts directed towards testing different template designs and slope profiles that would be most well received by nesting females would be of great interest.

Recommendations for nourishment profiles to be constructed with steeper slopes, thereby potentially mimicking the natural profile, should be approached with caution due to the negative influence of escarpments associated with beach nourishment projects (Bagley et al., 1994; Herren, 1999; Geomar Environmental Consultants, Inc., 2003a; Geomar Environmental Consultants, Inc., 2003b). While scarp formation occurs in both natural and nourished profiles; the practice of placing a nourished profile steeper than equilibrium ensures that the nourished profile will experience a greater incidence of scarping than natural profiles, due to the profile equilibration process (Dean, 2002). A mildly sloped template also extends the life expectancy of the project, thereby extending renourishment intervals and ultimately reducing the impacts to turtles by reducing the frequency of these projects. If escarpments prevent turtles from accessing the beach then the modifications to the slope are futile.

Early studies that experienced excessive scarp formation suggested multiple short nourishment intervals in lengths of 0.5 km. This alternative design is not the

most economically practical alternative from an engineering perspective because of logistical constraints. With proper sediment selection and applications, consideration should be made to increase these recommended intervals to larger continuous stretches not to exceed 5.0 km in length due to the length of renesting attempts (0 to 5 km) by loggerheads (Miller et al., 2003).

#### CONCLUDING REMARKS

Habitat conservation is viewed as a potential additional benefit of beach nourishment projects but can only occur in the absence of logistic or economic constraints. Coastal engineers are accountable for designing long lasting, economically optimal projects that provide extensive protection to valuable land and man-made structures. However, net benefits to the environment can be ensured by incorporating an understanding and concern for the environment into the design and construction of the project (Dean, 2002). The current understanding of beach nourishment activities and their impacts upon biotic systems has developed through the collaborative efforts of engineers and biologists. Properly implemented techniques can alleviate many of the potential negative impacts (Nelson and Dickerson, 1989). However, complex interactions of individual projects with unique biological systems warrant additional studies that would improve the design of beach nourishment practices from a

conservation perspective.

Much of Florida's human population accumulates along the coast and constitutes an enormous amount of wealth and political pressure for the protection against storms, sea level rise and erosion. Since a retreat of human development is unlikely and there is opposition to beach armoring, the future of beach nourishment in efforts to preserve coastal development and beaches is certain. Until other alternatives are developed, opposition to beach nourishment is futile. Biologists are obligated to work toward the evolution of beach nourishment in the preservation of nesting habitat suited for marine turtles.

Other environmental impacts to turtles caused by beach nourishment, not in the scope of this study, are the dangers associated with dredging activities and the covering of near shore rock outcrops used by foraging juveniles. Great disparity exists among marine turtle conservationists in that efforts must focus on terrestrial environments to ensure breeding grounds and aquatic environments for foraging. When conflict arises, the question of which warrants more protection, nesting habitat for adult turtles or foraging habitat for juvenile turtles, the answer brings about much disagreement. All things considered, the maintenance of long-term nesting beaches may take precedence for the reasons that adults faithfully return to particular nesting beaches and juveniles possess the ability to opportunistically find foraging habitat. In light of such truths,

conservation efforts should focus on acquiring undeveloped beaches and to ensure that beach nourishment projects generate a net benefit to marine turtles on developed beaches.

This study was constrained in time to two years post-nourishment and therefore has limitations on the interpretation of long-term effects. The importance of Brevard County to marine turtles merits future efforts and funding to continue the monitoring of this nourishment project and would increase the value of previous efforts and funding by providing valuable long-term post-nourishment data.

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