ASSESSMENT OF DIFFERENCES IN PHYSICAL PROPERTIES OF SAND ASSOCIATED WITH BEACH NOURISHMENT AND EFFECTS ON LOGGERHEAD SEA TURTLE (*Caretta caretta*) NESTING IN NORTHWEST FLORIDA

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my wonderful and supportive husband Burnie

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Beach nourishment is increasing in scope and execution as a response to coastal erosion in Florida. However, if sand used for nourishment has different properties than natural sand, then the beach ecosystem may be altered. Regulatory agencies maintain sand specifications for nourishment projects to monitor quality of fill materials. The reproductive effort of nesting sea turtles requires a suitable incubation environment: the effects of substandard fill material may be immediate (false crawl) or sublethal (poor incubation environment). Our objective was to determine if the physical properties of sand on post-nourishment beaches differed from natural beach sand, and whether any differences observed appeared to affect nesting loggerhead (Caretta caretta) sea turtles. Compaction, bulk density, water content, color (chroma and value), and grain size distribution were analyzed on seven pairs of nourished beaches and natural beaches in northwest Florida in 2006. We hypothesized that any differences in these physical properties on nourished versus natural beaches could affect loggerhead sea turtle nesting success. While compaction measurements are often the primary method of evaluating beaches post-nourishment, measuring shear resistance may provide a more complete picture of a sea turtle's perception of the beach during nest chamber excavation. In summer 2007, shear resistance measurements

were taken alongside compaction readings using a device developed for this study. Our shear vane device was more successful at depth than on the surface, and results were repeatable on the same beach over time. We saw a general trend of the physical properties of several recently nourished beaches returning over time to a state more similar to that of the native beach. The nesting density, hatching success, and emerging success of loggerhead sea turtles did not appear to be adversely affected by beach nourishment. Overall, it appears that the processes in place for nourishing and maintaining beaches in northwest Florida are not incompatible with loggerhead sea turtle nesting, and implementing shear resistance measurements as a management tool following beach nourishment projects would provide useful information to coastal managers which could be beneficial to nesting loggerhead sea turtles.

CHAPTER 1
INTRODUCTION

Beach nourishment is the placement of large amounts of sand on a beach to mitigate coastal erosion by extending the shoreline seaward or by reconstructing a dune (DEAN, 2002). Nourishing beaches provides protection of urban areas, recreational and tourism benefits, and if done properly, ecological benefits (LUCAS and PARKINSON, 2002). Because beach nourishment can alter abiotic and biotic elements of the ecosystem, it has the potential to significantly affect all organisms in the coastal system. The effects can be harmful or advantageous, and can be either temporary or long-term depending upon the nature of the system in question (DEAN, 2002). Through responsible design and monitoring, coastal managers seek to minimize negative impacts of beach nourishment and maximize recreational and economic benefits.

Habitat alteration within an ecosystem is frequently a major cause of reduced species diversity (EHRENFELD, 1970). Environmental changes occur naturally but can be interfered with, impeded by, or accelerated by human actions (SOUTHWICK, 1996). Severe storms and sea level rise cause coastal erosion, which means that the shoreline retreats inland (WALTON, 1978). Human actions, such as the creation of artificial navigational inlets, can speed this natural recession by inhibiting the littoral transport and accretion of sands (DOUGLAS, 2002, KRIEBEL *et al.*, 2003). Receding coastlines threaten human structures and recreation, thus increasing the desire to nourish beaches (PILKEY, 1991, OLSEN and BODGE, 1991).

A variety of organisms including invertebrates, fish, birds, and sea turtles, inhabit the coastal areas at some point in their life cycle. Beach nourishment has the potential to significantly impact all of these groups. Invertebrates such as coquina clams (*Donax spp*.) and mole crabs (*Emerita talpoida*) comprise a substantial portion of the prey base for ecologically and economically valuable coastal birds and fish. Schmitt and Haines (2003) found that the impact of beach nourishment on invertebrate populations is generally negative in the short term. Long-term recovery time, however, depends on the duration and timing of the nourishment project and the interval between nourishment episodes. Because invertebrates comprise a large portion of the prey base for many shoreline fish, their loss could mean a reduction in fish populations. Nourishment also stirs up sediments near the project site, which can cause gill damage and even death of near-shore fishes (SCHMITT and HAINES, 2003).

Female turtles assess a nesting beach from the water before coming ashore to nest (CARR and OGREN, 1960, HENDRICKSON, 1982). Loggerhead sea turtles tend to favor steeply-sloped, moderate to high energy beaches that have moderately-sloped offshore approaches (PROVANCHA and EHRHART, 1987, WOOD and BJORNDAL, 2000). Geomorphology and dimensions of the beach are considered important factors in nest site selection (MORTIMER 1982, JOHANNES and RIMMER, 1984), as are depth of offshore waters (HUGHES, 1974, MORTIMER, 1982), texture of the sediment (STANYCK and ROSS, 1978, MORTIMER, 1990), and artificial lighting on the beach (MORTIMER, 1982, WITHERINGTON, 1992, SALMON *et al.,* 1995). All marine turtle species exhibit a common core sequence of nesting behaviors. The female emerges from the water, crawls up the beach, excavates a body pit, digs out an egg chamber, oviposition occurs, and finally the egg chamber and body pit are filled in with sand prior to her return to the ocean (MILLER *et al.,* 2003). Nourishing beaches may influence nest digging, potentially causing the shape of the nest to be altered, if the nourished beach has different sand properties than the natural beach (CARTHY, 1996).

Sediment characteristics play a vital role in the reproductive success of turtles and can profoundly influence embryological development and survival (BUSTARD, 1973, MCGEHEE, 1979, PACKARD AND PACKARD, 1988). Both ambient nest temperature and incubation duration are impacted by changes in sediment color, grain size, and grain shape resulting from beach nourishment (MILTON *et al.*, 1997). Because the sex of marine turtles is determined by nest incubation temperature, with a higher proportion of males produced at lower temperatures and a higher proportion females at higher temperatures, if a beach nourishment project alters physical properties of the sand capable of influencing the incubation temperature, sex determination of turtle hatchlings could be directly affected (MROSOVSKY *et al.*, 1998). Although sea turtle nests deposited onto nourished beaches tend to hatch successfully (EHRHART and RAYMOND, 1983, Raymond, 1984, Wolf *et al.*, 1986, Nelson *et al.*, 1987), monitoring of hatchling sex ratios is important from a conservation standpoint (MROSOVSKY and YNTEMA, 1980, MORREALE *et al.*, 1982) because they could alter the population sex ratio, thereby affecting the reproductive success of the population (HANSON *et al.*, 1998). Approximately 90 percent of the loggerhead nests in the United States occur in Florida (Murphy and Hopkins, 1984) where the sex ratios of hatchlings and immature sea turtles are significantly female biased (MROSOVSKY and PROVANCHA, 1989, 1992, WIBBLES *et al.*, 1991).

Beach nourishment projects can alter hatchling development by changing beach characteristics such as sand compaction, nutrient availability and the gaseous, hydric, and thermal environments of the nest chamber (CRAIN *et al.*, 1995). Grain size and sorting are important determinants of gas exchange, moisture content, and other vital characteristics of the nesting environment for developing sea turtles (ACKERMAN, 1980, NELSON and DICKERSON, 1989, MORTIMER, 1990, ACKERMAN *et al.*, 1992). Nourished beaches have demonstrated positive impacts (BROADWELL, 1991, EHRHART and HOLLOWAY-ADKINS, 2000, EHRHART and ROBERTS, 2001), negative impacts (EHRHART, 1995, ECOLOGICAL ASSOCIATES INC., 1998), or no apparent impact (RAYMOND, 1984, NELSON *et al.*, 1987, BROADWELL ,1991, STEINITZ *et al.*, 1998) on marine turtle hatchling success.

The goal of this study was to compare physical characteristics of sand on natural and nourished beaches including compaction, shear resistance, bulk density, water content, soil color, and grain size distribution and to relate any differences in these physical sand characteristics to differences in loggerhead sea turtle (*Caretta caretta*) nesting success in northwest Florida.

CHAPTER 2
LOOKING AT SAND FROM A SEA TURTLE'S PERSPECTIVE: DEVELOPMENT OF A NOVEL SHEAR VANE DEVICE TO COMPARE SHEAR RESISTANCE OF SAND ON NATURAL AND NOURISHED BEACHES

Introduction

Following beach nourishment projects, the U.S. Fish and Wildlife Service requires that beach compaction be measured to ensure that the nourished sand provides viable habitat for sea turtle nesting (COOPER, 1998). Steinitz *et al.* (1998) found that on nourished beaches, nesting success of sea turtles was significantly and negatively correlated with increasing compaction at a depth of 20 cm, while natural beaches experienced no correlation between compaction and nesting success. Compaction is also known to increase with sand depth (NELSON *et al.,* 1987). This parameter could influence nest excavation and conditions such as temperature, moisture, and ease of gas exchange between incubating sea turtle eggs and their surrounding environment. A physical monitoring workshop undertaken at the 20th Annual Symposium on Sea Turtle Biology and Conservation cited beach hardness as the most important factor in measuring impacts of beach nourishment (PARKINSON, 2000).

Between 30 and 40 percent of the time, loggerhead sea turtles emerging onto a nesting beach return to the ocean without excavating a nest chamber (STONEBURNER AND RICHARDSON, 1981, EHRHART AND RAYMOND, 1983, WILLIAMS-WALLS *et al.,* 1983), a behavior known as a false crawl. Females may also perform a false dig, which involves emerging from the water, digging a nest chamber, and abandoning it without laying any eggs. False crawls and false digs could be caused by a turtle's "readiness" to lay, physical characteristics of the beach, temperature of the beach sediment, and disturbances such as the presence of predators or lights on the beach (MANN, 1978, FLETEMEYER, 1981, STONEBURNER and RICHARDSON, 1981, EHRHART and RAYMOND, 1983). If the physical consistency of a nourished beach is too hard, females may be forced to spend more time on the beach nesting, which is physiologically taxing and increases potential exposure to disturbances and predation, all of which could lead to a false dig (NELSON and DICKERSON, 1989).

Beach compaction is commonly measured using a device called a cone penetrometer, which measures the penetration resistance associated with pressing a conical point of known volume down into the soil until it is just below the soil surface (ELE INTERNATIONAL, 2004). While compaction is one important factor to examine on nourished beaches, it may not provide a complete picture of how the sand is perceived by a nesting sea turtle crawling onto the beach and excavating a body pit. Because nesting sea turtles follow a core sequence of behaviors that is more complex than simply inserting their limbs straight down into the sand, measuring other properties such as shear resistance may provide additional information about a sea turtle's perception of the beach (MILLER *et al.,* 2003). Shearing resistance is a consequence of the pressure between sand grains and is influenced by grain size distribution, grain shape and orientation, and weight of overburden (NELSON *et al.,* 1987). Synonyms for shear resistance are beach hardness and compaction (PARKINSON, 2000). For the purposes of this study, shear resistance will refer to the force required to move sand in a horizontal direction, while compaction will be defined as the force required to penetrate the sand in a vertical direction. By measuring shear resistance in addition to sand compaction, we may gain insight about why sea turtles decide to false crawl or false dig on certain beaches.

In summer 2007, we measured shear resistance as a separate entity from beach compaction using a slightly modified, enlarged version of a shear vane apparatus. The goal of conducting these shear resistance procedures was to provide insight about how nesting sea turtles perceive the beach while crawling up and digging a nest chamber. Work was conducted on 7 pairs of natural (never nourished) and nourished (at least one nourishment project had occurred or was planned to begin before the study date) beaches in northwest Florida.

Methods

Selection of Sampling Sites

Pairs of natural and nourished beaches were chosen based on two criteria: geographic orientation and distance apart. Each pair of beaches needed to have the same orientation, and pairs needed to be spaced closely enough to each other to be comparable but not so close that a significant amount of sand was likely to mix between them. Consultations with U.S. Fish and Wildlife Service biologists helped to finalize our sampling site selection. Sampling was confined to the Florida panhandle with sites ranging from Alligator Point in the east to Langdon Beach on Gulf Islands National Seashore property in the west.

Compaction and Shear Resistance

U.S. Fish and Wildlife Service requirements dictate that reasonable measures of minimizing the effects of nourishment on sea turtles include three years of beach monitoring after a nourishment project. Protocol states that sand compaction should be measured using a cone penetrometer at 500 foot (152m) intervals along the nourished region and at three evenly spaced stations; one at the dune or bulkhead line, one at the high water line, and one directly between these reference points. At each station, the Penetrometer should be pressed to depths of 6, 12, and 18 inches (15.24cm, 30.48cm, and 45.72cm), using three replicate measurements per location. Replicate measurements should be taken as close together as possible without interacting with previous measurements. The three replicate compaction readings for each location should be averaged to yield final values for each depth at each station. Reports must include 27 compaction values for each beach monitored (COOPER, 1998). For this study, depth of measurements, replication, and spacing of transects followed the protocol above with regard to both compaction and shear measurements.

Shear resistance measurements were taken using a device and techniques developed in this course of study. An enlarged shear vane was constructed from steel. The four steel blades of the shear vane were welded at approximately 90º angles to each other. Each blade measured approximately 4.75 cm wide by 7.25 cm tall, 2.5 times larger than a standard shear vane (New Zealand Geotechnical Society, 2001). The blades were welded to a 12 inch (30.48 cm) steel shaft with a ¼-inch male fitting at the top. An 8 cm long, 2 cm thick steel cylinder with an opening slightly wider than the diameter of the vane shaft was welded to the center of a 12 inch by 12 inch (30.48 cm by 30.48 cm) steel plate designed to provide stability to the shear vane during measurements (Figure 2-1). Preliminary tests were done using several prototypes in sand at various depths, and the 2.5 times enlarged shear vane size was found to deliver the most consistent results within the operating range of the torque wrench used.

Our enlarged shear vane was first inserted through the cylinder in the center of the steel plate for stability (Figure 2-1). The shear vane was able to rotate freely within the cylinder, minimizing unnecessary horizontal movement. The plate was placed flat onto the surface of the sand and secured into place using a metal hammer. A TECH1 ¼-inch drive Snap-on® TECHWRENCH® electronic torque wrench was attached to the top of the shear vane apparatus and rotated 90º using one constant motion (Figure 2-2). The torque reading was recorded in Newton-meters and reported as the shear resistance for that sample.

The area ratio of our enlarged shear vane blades was calculated as a percentage using the equation area ratio = $[8T(D-d) + \pi d2] / \pi D2 \times 100$, where D is the overall width of the vane in millimeters, T is the thickness of the blades in millimeters, and d is the diameter of the vane rod in millimeters. In determining the area ratio, the average of the two blade widths was reported as overall width D, and the average of the four blade thicknesses at the midpoint of each blade was reported as the thickness of the blades T. Rod diameter d was measured at the midpoint of the rod. A Westward® IP-54 Electronic Caliper, model number 2ZA60, was used to obtain dimensions of the shear vane and extension rod to the nearest 0.01 mm. According to New Zealand Geotechnical Society guidelines for hand held shear vane testing, the area ratio should not exceed 25% (2001). The area ratio of our shear vane was calculated as 9.05%, which is well below the 25% limit, indicating that our shear vane meets the area ratio requirement.

Shear resistance measurements were also used to determine the vane shear strength of soil, in kilopascals (kPa); which was calculated from the equation $\tau = M/K$, where M is the torque required to shear the soil in Newton-meters, and K is a constant dependent on the dimensions and shape of the shear vane. The constant K was calculated as $K = 0.33 = \pi D2H/2 \text{ x } (1 + D/3H) \text{ x } 10\text{-}6$; where D is the overall width of the vane in millimeters, and H is the height of the vane in millimeters (New Zealand Geotechnical Society, 2001). A Westward® IP-54 Electronic Caliper, model number 2ZA60, was used to obtain dimensions of the shear vane and extension rod to the nearest 0.01 mm. In determining the constant K, the average of the two blade widths was reported as overall width D, and the average of the four blade heights at the midpoint of each blade was reported as the height of the vane H.

Because of the relatively large proportion of zero values in the data, a Wilcoxon Sign-Rank test was used to statistically compare the shear resistance of natural versus nourished beaches. Compaction data did not follow a normal distribution; therefore the Wilcoxon Sign-Rank test was also used to compare those values. The statistical program JMP was used to perform all statistical tests.

Results

Table 2-1 shows the raw data; all shear resistance measurements (in Newton-meters) taken for all beaches. Table 2-2 displays the proportion of zeroes, or the proportion of the time that the device did not register a reading because the sand was too soft. These proportions are summarized in Table 2-3, which reports the proportion of zero readings for all beaches, all natural beaches, and all nourished beaches separately. When all beaches were included, the overall success of the shear vane at registering a reading above zero was 68%. However, 78% of the zero readings occurred at the surface, while the readings taken at 6 inches and 12 inches (15.24cm and 30.48cm) had a much lower proportion of zero values. On nourished beaches, surface measurements registered a zero value 93% of the time. The mean vane shear strength of soil and standard deviation for each beach are reported Table 2-8.

Of the seven nourished beaches that we studied, two were not actually nourished by the time of the study. Four of the remaining five pairs of natural versus nourished beaches showed no statistically significant difference in overall shear resistance, while only two of the five pairs had no significant difference in overall compaction. Navarre beach, which was nourished most recently (2006) did have a significantly different overall shear resistance as compared to its natural counterpart, Santa Rosa. Overall shear resistance may not be the best indicator of whether natural versus nourished beaches are significantly different because of the relatively high proportion of zero readings at the surface. However, when surface readings were excluded from the analysis, results were exactly the same for all beach pairs (Table 2-6).

To test the repeatability of using the enlarged shear vane device, we sampled both Cape San Blas beaches twice in 2007. No significant differences were found in the overall shear resistance over the course of the season (Table 2-7). When surface readings were excluded from the analysis, there was not enough data to compare Cape San Blas natural beach statistically over the course of the season because we were only able to sample two of three transects a second time due to erosion. The Cape San Blas not yet nourished beach was not significantly different over the course of the season when surface readings were excluded from the analysis. Sand compaction was significantly different on the natural Cape San Blas beach over the course of the season, probably due to the large amount of erosion that occurred on that beach during the season.

We found no significant linear correlation between beach compaction and shear resistance measurements. Figure 2-3 shows a linear regression plot of shear versus compaction, with an R^2 correlation coefficient of 0.19. Table 2-9 shows overall compaction values and results for each depth range measured.

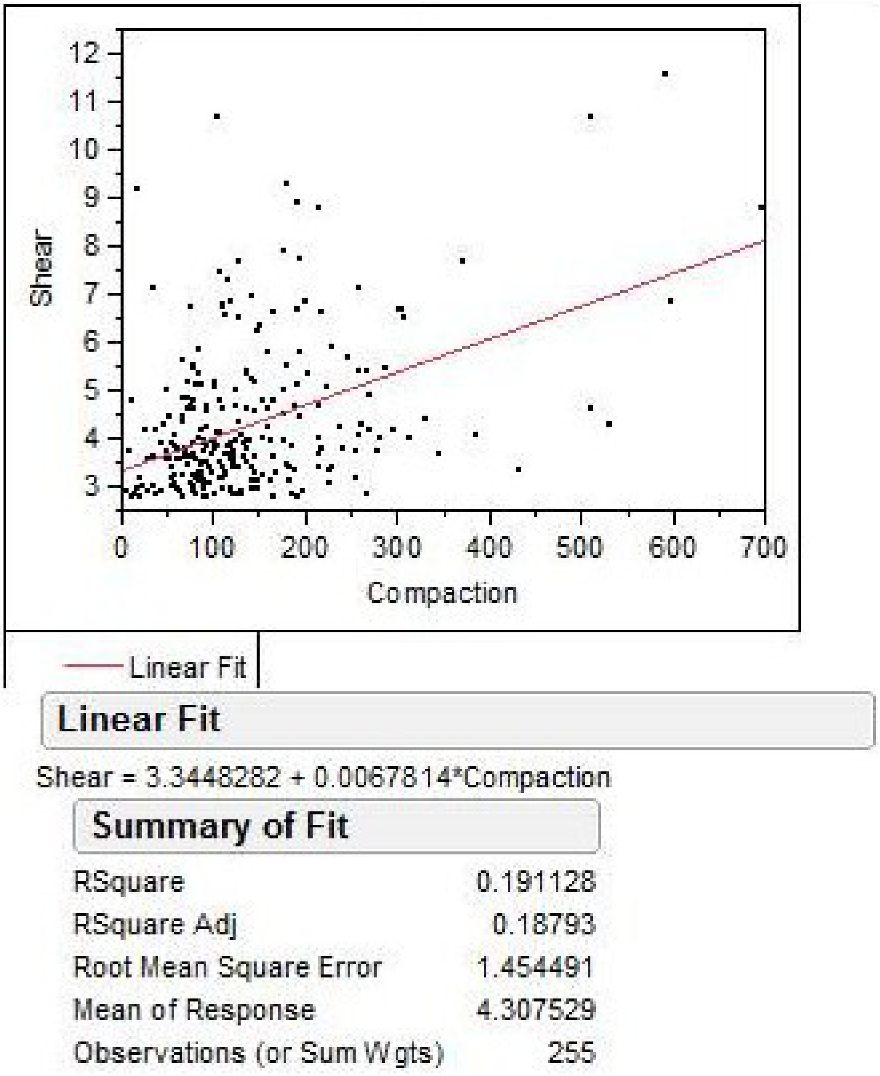
Discussion

One indicator of the success of our shear vane device was the proportion of the time that the device gave a reliable reading. Our device did not register a reading due to soft surface sand more than half the time, indicating that it is a more useful tool at depth than on the surface, particularly on nourished beaches. Perhaps using a shear vane that had even larger blades would yield more reliable readings at the surface. Because shear resistance may be present at nest depth even when surface sand has no shear measurable resistance, beach monitoring protocol following a nourishment project should include the use of an enlarged shear vane device at nest depth. Our device detected no difference in shear resistance on either Cape San Blas beach over the course of the season, giving us confidence that our shear vane device delivered repeatable results.

Because our findings suggest that sand compaction does not exhibit a positive linear correlation with shear resistance, we conclude that measuring shear resistance as a separate entity from beach compaction is important. Compaction did tend to be lower on the surface than at depth in most cases, but the readings did not always increase with depth after the surface reading. The graph also indicates that there is a lower detectability limit for the specific shear vane size and torque wrench that we used. Measuring shear resistance gives us additional information about the physical condition of sand placed on a beach during nourishment and may provide useful insight from a sea turtle conservation management perspective.

Figure 2-1. Enlarged shear vane device used to conduct shear resistance measurements, view from underneath.

Figure 2-2. Enlarged shear vane device used to conduct shear resistance measurements, view from above.



Linear Fit

Shear = 3.3448282 + 0.0067814*Compaction

Summary of Fit

RSquare	0.191128
RSquare Adj	0.18793
Root Mean Square Error	1.454491
Mean of Response	4.307529
Observations (or Sum Wgts)	255

Figure 2-3. Linear Regression plot of shear versus compaction.

Table 2-1. Shear resistance values for individual beaches in Newton-meters.

Shear Resistance (Nm) - Raw Data																											
Beach	Surface									15.24 cm (6 inch) depth									30.48 cm (12 inch) depth								
Cape Nat.	12.43	3.75	4.75	6.76	6.49	3.25	11.49	3.29	-	5.40	5.34	3.98	10.62	3.94	4.24	8.74	4.58	3.03	-	7.59	4.14	-	4.23	3.33	-	6.79	4.00
Cape Nour.	3.39	-	2.74	2.95	-	-	3.32	-	-	4.54	2.87	3.87	3.95	3.10	3.67	3.62	3.52	-	4.84	4.62	3.81	3.67	-	5.32	4.01	4.01	-
Alligator Point	3.31	3.89	-	6.78	-	4.78	3.97	3.31	3.35	9.20	7.08	3.89	10.61	8.84	6.56	6.42	5.63	4.39	9.10	4.12	6.73	9.58	6.63	7.39	7.07	7.63	8.74
Bald Point	-	-	-	-	-	-	-	-	-	3.42	4.10	2.89	3.85	-	3.02	3.07	-	-	3.34	3.96	4.15	3.36	2.89	-	2.71	-	-
Panama City	-	-	-	-	-	-	2.93	-	-	3.60	4.74	4.36	3.24	2.75	4.72	3.65	3.24	3.16	4.15	3.57	3.77	2.80	-	3.53	3.77	4.53	2.85
Camp Helen	-	-	-	-	-	-	-	-	-	-	3.18	4.06	-	3.16	-	3.01	3.34	3.60	3.27	3.58	3.82	3.51	3.59	3.52	-	3.90	5.04
Henderson	-	-	-	-	-	-	-	-	-	3.50	4.52	3.55	2.89	3.59	4.96	3.83	5.26	2.85	3.34	3.73	3.24	3.10	3.74	3.70	3.36	4.62	2.83
Okaloosa	2.85	-	-	-	-	-	-	-	-	3.78	3.15	3.12	2.76	3.76	4.22	-	3.43	3.14	3.67	3.52	3.09	3.28	3.76	2.76	3.41	3.60	3.58
Grayton	-	-	-	-	-	-	-	-	-	-	3.07	2.73	3.46	4.98	4.54	4.61	4.95	6.14	3.58	2.78	4.43	4.72	3.05	3.85	3.18	5.12	6.66
Sandestin	3.85	-	-	-	-	-	-	-	-	2.97	2.73	7.68	6.90	3.06	7.25	2.88	3.87	6.53	2.99	5.78	6.61	5.26	4.80	3.25	5.08	5.75	3.75
Pensacola	-	-	-	-	-	-	-	-	-	3.43	3.01	4.05	3.80	4.10	3.78	4.71	4.63	2.82	3.86	4.94	3.90	3.91	5.47	3.49	4.56	2.79	2.91
Langdon	-	-	-	-	-	-	-	-	3.69	3.11	2.92	3.52	2.76	3.89	4.57	2.71	4.37	2.95	3.60	5.11	6.67	-	-	4.41	3.23	4.10	5.55
Navarre	-	-	-	-	-	-	-	-	-	5.73	2.78	4.26	6.47	3.92	5.38	5.02	6.30	3.52	-	-	2.80	5.30	4.28	7.84	5.86	3.75	5.19
Santa Rosa	2.78	2.88	-	2.72	-	2.84	-	-	3.10	5.07	4.14	2.81	4.10	4.61	4.52	3.67	3.38	3.06	5.12	-	5.43	3.54	3.57	3.35	3.42	2.81	5.35

Table 2-2. Proportion of zero values (too soft to read) and summary statistics for individual beaches.

Beach	Cape Nat.	Cape Nour.	Alligator Point	Bald Point	Panama City	Camp Helen	Henderson	Okaloosa	Grayton	Sandestin	Pensacola	Langdon	Navarre	Santa Rosa
Proportion of zero readings (too soft to read)														
Surface	0.11	0.56	0.22	1.00	0.89	1.00	1.00	0.89	1.00	0.89	1.00	0.89	1.00	0.44
6 inch depth	0.00	0.11	0.00	0.33	0.00	0.33	0.00	0.11	0.11	0.00	0.00	0.00	0.00	0.00
12 inch depth	0.33	0.22	0.00	0.33	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.22	0.22	0.11
Overall	0.15	0.30	0.07	0.56	0.33	0.48	0.33	0.33	0.37	0.30	0.33	0.37	0.41	0.19
Mean Torque														
Surface	6.53	3.10	4.20	N/A	2.93	N/A	N/A	2.85	N/A	3.85	N/A	3.69	N/A	2.86
6 inch depth	5.54	3.64	6.96	3.39	3.72	3.39	3.88	3.42	4.31	4.87	3.81	3.42	4.82	3.93
12 inch depth	5.01	4.33	7.44	3.40	3.62	3.78	3.52	3.41	4.15	4.81	3.98	4.67	5.00	4.07
Overall	5.75	3.78	6.36	3.40	3.63	3.61	3.70	3.38	4.23	4.79	3.90	3.95	4.90	3.74
Standard Deviation														
Surface	3.62	0.31	1.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.15
6 inch depth	2.50	0.52	2.24	0.49	0.72	0.38	0.86	0.47	1.14	2.15	0.65	0.70	1.28	0.76
12 inch depth	1.73	0.61	1.63	0.57	0.59	0.55	0.52	0.32	1.23	1.24	0.89	1.20	1.63	1.05
Overall	2.74	0.69	2.21	0.51	0.65	0.51	0.71	0.40	1.15	1.67	0.76	1.08	1.39	0.91

Table 2-3. Proportion of zero values (too soft to read) on natural, nourished, and all beaches.

Proportion of zero readings (too soft to read)

	All Beaches	All Natural Beaches	All Nourished Beaches*
Surface	0.78	0.78	0.93
6 in depth	0.07	0.11	0.02
12 in depth	0.12	0.16	0.07
Overall	0.32	0.35	0.34

*Excluding Alligator Point and Cape Nourished, which have not yet been nourished.

Table 2-4. Shear resistance values on Cape San Blas beaches over the course of the 2007 season.

Shear Resistance (Nm) - Raw Data

Beach	Date	Surface									15.24 cm (6 inch) depth									30.48 cm (12 inch) depth								
Cape	5/10/2007	12.43	3.75	4.75	6.76	6.49	3.25	11.49	3.29	-	5.40	5.34	3.98	10.62	3.94	4.24	8.74	4.58	3.03	-	7.59	4.14	-	4.23	3.33	-	6.79	4.00
Natural	8/12/2007	3.55	3.07	-	3.93	3.39	2.91	N/A	N/A	N/A	4.74	3.52	4.61	5.00	6.70	4.17	N/A*	N/A	N/A	10.30	7.06	5.64	7.62	7.97	7.80	N/A	N/A	N/A
Cape	5/11/2007	3.39	-	2.74	2.95	-	-	3.32	-	-	4.54	2.87	3.87	3.95	3.10	3.67	3.62	3.52	-	4.84	4.62	3.81	3.67	-	5.32	4.01	4.01	-
Nourished	8/12/2007	-	-	-	-	-	-	-	-	-	2.83	4.82	2.71	4.16	4.05	3.77	4.97	3.36	4.16	5.01	4.50	5.74	4.29	5.18	3.75	3.17	5.53	3.86

Table 2-5. Proportion of zero values (too soft to read) and summary statistics for Cape San Blas beaches over the course of the 2007 season.

Beach	Cape Natural		Cape (Not Yet Nourished)	
Sampling Date	5/10/07	8/12/07	5/11/07	8/12/07
Proportion of zero readings (too soft to read)				
Surface	0.11	0.17	0.56	1.00
6 inch depth	0.00	0.00	0.11	0.00
12 inch depth	0.33	0.00	0.22	0.00
Overall	0.15	0.06	0.30	0.33
Mean Torque				
Surface	6.53	3.37	3.10	N/A
6 inch depth	5.54	4.79	3.64	3.87
12 inch depth	5.01	7.73	4.33	4.56
Overall	5.75	5.41	3.78	4.21
Standard Deviation				
Surface	4.30	6.02	3.78	N/A
6 inch depth	5.58	2.56	2.75	0.00
12 inch depth	4.90	3.75	4.34	5.02
Overall	4.92	4.30	3.80	4.27

Table 2-6. Comparison of compaction and shear resistance on natural and nourished beaches.

Physical Property of Soil	Beach Pairs Compared						
	Navarre*	Pensacola*	Panama City*	Okaloosa*	Sandestin*	Cape*	Alligator Point*
2007	Santa Rosa	Langdon	Camp Helen	Henderson	Grayton	Cape	Bald Point
Compaction	NS	*	**	**	NS	**	**
Shear Resistance	*	NS	NS	NS	NS	**	**
Shear Resistance (excluding surface values)	*	NS	NS	NS	NS	**	**
*Year of Last Nourishment	2006	2005	2005	2004	1988	Future Plans	Future Plans

Table 2-7. Comparison of compaction and shear resistance on Cape San Blas beaches over the course of the 2007 season.

Beach:	Cape (Natural)	Cape (Not Yet Nourished)
Compaction	**	NS
Shear Resistance	NS	NS
Sampling Dates:	5/10/07, 8/12/07	5/11/07, 8/12/07

Table 2-8. Vane shear strength of soil (kPa) for all beaches measured in 2007.

2007	Vane Shear Strength of Soil		
Beach	Mean	Standard Deviation	*Year of Last Nourishment
Navarre*	14.85	4.22	2006
Santa Rosa	11.33	2.75	
Pensacola*	11.81	2.30	2005
Langdon	11.97	3.28	
Panama City*	11.00	1.97	2005
Camp Helen	10.95	1.53	
Okaloosa*	9.71	2.63	2004
Henderson	11.21	2.15	
Sandestin*	14.51	5.05	1988
Grayton	12.81	3.50	
Cape* 5/11/07	11.45	2.08	N/A
Cape 5/10/07	17.41	8.30	Future Plans
Cape* 8/12/07	12.77	2.67	N/A
Cape 8/12/07	16.40	6.49	Future Plans
Alligator*	19.27	6.70	N/A
Bald	10.29	1.54	Future Plans

Table 2-9. Mean compaction values (Newtons) for each depth range measured.

Mean Compaction (Newtons) by Sampling Depth														
2006	Cape Nat.	Cape Nour.	Bald Point	Alligator Point	Camp Helen	Panama City	Henderson	Okaloosa	Grayton	Sandestin	Langdon	Pensacola	Santa Rosa	Navarre
Overall	290.19	187.94	67.21	167.73	75.67	108.29	62.75	71.52	89.80	98.58	61.99	101.87	67.38	104.69
0-15.24cm	314.33	104.46	22.68	148.97	20.13	21.08	13.26	26.04	31.20	15.17	25.02	11.07	19.38	9.05
15.24-30.48cm	303.36	232.23	73.95	203.48	91.57	160.47	86.99	90.03	122.61	153.07	76.93	152.32	80.98	124.37
30.48-45.72cm	252.89	227.12	104.99	148.61	115.32	143.32	88.01	98.49	115.58	127.51	84.01	142.20	101.80	180.64
2007														
Overall	167.37	76.31	70.19	146.50	73.42	105.20	58.69	25.09	70.21	65.50	32.21	51.16	53.88	40.59
0-15.24cm	136.40	21.88	14.80	76.19	18.10	18.42	19.75	5.86	20.07	11.02	12.03	6.28	19.97	7.93
15.24-30.48cm	188.95	84.23	83.06	173.40	99.83	142.68	78.90	39.19	87.63	91.95	40.36	70.97	74.27	63.09
30.48-45.72cm	181.47	122.83	112.71	189.91	102.33	154.50	77.41	30.24	102.91	93.54	44.24	76.24	67.40	50.74

CHAPTER 3

ASSESSMENT OF DIFFERENCES IN PHYSICAL PROPERTIES OF SAND ON NATURAL AND NOURISHED BEACHES IN NORTHWEST FLORIDA

Introduction

Erosion and sea level rise threaten structures along developed coastlines each year. The beach acts as a natural barrier, protecting developed areas during storm events. Beaches are dynamic systems that erode during winter months, accrete in the summer, and shift constantly due to waves, currents, and wind (SCHMITT and HAINES, 2003). The forces of nature move and reallocate portions of the shoreline considerably over time, sometimes causing accretion or even a temporary disappearance. Generally, sand is pulled offshore in winter and during storm events and pushed back onshore in spring and summer. Because of the constant pressure of natural forces, beaches, especially on barrier islands, naturally migrate. Hardened structures imposed by humans may alter this natural cycle by impeding the transfer of sand needed for beach accretion. Human engineered solutions such as sea walls, groins, jetties, and other hardened structures intensify the problem. Beach nourishment is currently the most accepted engineered system for the protection of natural and man-made areas from the effects of erosion (JONES and MANGUN, 2001).

Significant alterations in beach substrate properties could occur if fill sediment from physically incompatible sources is used. Beach nourishment can alter the density, compaction, shear resistance, moisture content, beach slope, sediment color, grain size, grain shape, and mineral content of sediment in the beach system (PIATKOWSKI, 2002). Differences in particle size can directly impact the shear resistance of the sediment, making the beach relatively harder after a nourishment project. Harder or more compacted sand result primarily from the angular, finer grain sediment dredged out of stable offshore borrow pits. Softer, less compacted beaches result from smoother, coarse sediment dredged from high energy borrow sites such as inlets

(NELSON and DICKERSON, 1989). Sediment used for beach nourishment projects is obtained from three main sources: inlets, channels, and offshore borrow sites (CRAIN *et al.*, 1995). Potential borrow sites of beach-compatible sand for Florida's beaches include offshore interreefal sedimentary infills, upland dunes, sand sheet inland deposits, and oolithic sand from the Bahama Banks. The cost of finding and transporting beach compatible sand may be a limiting factor in future beach nourishment projects in Florida, and alternatives such as recycled glass have been proposed as potential beach fill material (MAKOWSKI and RUSENKO, 2007).

Management agencies that regulate beach nourishment projects maintain specifications regarding the quality of fill material used. Our objective was to determine whether there were significant differences in physical properties of sand between natural and nourished beaches in northwest Florida. Specifically, compaction, shear resistance, bulk density, water content, grain size distribution, and soil color were measured.

Methods

Selection of Sampling Sites

We sampled 14 beaches in northwest Florida in 2006 and again in 2007. Seven of the beaches were considered natural, meaning those beaches have never been nourished and no current plans for nourishment currently exist. The other seven "partners" had either undergone or planned at least one beach nourishment project. Northwest Florida was chosen because of the relatively large number of nourishment projects that are planned or have already taken place in that region. Also, these beaches are utilized by threatened loggerhead sea turtles (*Caretta caretta*) for nesting each year.

Pairs of natural and nourished beaches were selected based primarily on two criteria: geographic orientation and distance apart. Pairs of beaches needed to face the same direction and be spaced closely enough to each other to be comparable but not so close that a significant amount of sand was likely to mix between natural and nourished sites. Consultations with U.S. Fish and Wildlife Service biologists helped to finalize the sampling site selection process. Sampling was constrained to the Florida panhandle, and sites ranged from Alligator Point in the east to Langdon Beach on Gulf Islands National Seashore property in the west. Table 3-1 lists all seven pairs of natural and nourished beaches sampled in this study. Figure 3-1 displays the geographic location of all of the beaches on a map. Navarre beach was sampled twice in 2006 to observe change in physical properties on the same beach over the course of the season. Both Cape San Blas natural beaches were measured twice in 2007 for the same reason. Table 3-2 lists the nourishment method and years of nourishment for the seven nourished beaches sampled in this study.

Compaction and Shear Resistance

According to U.S. Fish and Wildlife Service requirements, reasonable measures of minimizing the effects of nourishment on sea turtles include three years of beach monitoring following a nourishment project. Protocol mandates that compaction should be measured using a cone penetrometer at 500 foot (152m) intervals along the nourished area and at three evenly spaced stations; one at the dune or bulkhead line, one at the high water line, and one directly between these reference points. At each station, the Penetrometer should be pressed to depths of 6, 12, and 18 inches (15.24cm, 30.48cm, and 45.72cm), with three replicate measurements per location. Replications should be done as close together as possible without interacting with previously measurements. The three replicate compaction values for each location are to be averaged to yield final values for each depth at each station. Reports must include 27 compaction values per each transect (COOPER 1998). For this study, depth of measurements and spacing of transects followed the protocol above for both compaction and shear measurements. Figure 3-2 illustrates the sampling regime used. A total of 27 measurements per beach were taken on each beach. Each measurement was based upon an average of three replicate measurements at the same depth and location. Portable Global Positioning System (GPS) units were used to mark each sampling location. Shear resistance measurements were taken using techniques described in Chapter 2.

Bulk Density and Water Content

Standard methods of bulk density and water content determination were obtained from U.S. Fish and Wildlife Service requirements and from a report by Steinitz *et al.* that utilized similar procedures (1998). Core samples for these measurements were obtained at intervals of 0 to 15.24cm, 15.24 to 30.48cm, and 30.48 to 45.72cm below the surface at each location used for shear resistance measurement. Portable Global Positioning System (GPS) units were used to record each sampling location. One Ziploc bag was labeled for each sample to be collected (27 total per beach in 2006). A mallet was used to drive a PVC pipe (henceforth known as the “core sampler”) of known volume (308.889 cm3) directly into the ground, filling it completely to collect a core sample 15.24 centimeters in depth. The top of the core sampler was covered with a wide spatula to ensure that sand particles did not escape through the top. Sand was removed around the core sampler, and the outside was wiped clean with a rag. A wide spatula was then carefully placed underneath it, completely flush with the bottom of the tube. The spatula was then removed from the top of the core sampler and carefully replaced with a Ziploc bag. The sample was then inverted into the bag. Using a narrow spatula, excess sand grains were scraped into the Ziploc bag from the inside of the core sampler. Samples were placed into an un-iced cooler to avoid extreme heat or sun during transport. The inside of the core sampler and all spatulas were wiped clean with a rag between samples. These steps were repeated for depth ranges of 15.24 to 30.48 cm and 30.48 to 45.72 cm at each sampling location. Figure 3-2 outlines the sampling regime used, and the same locations were used for core sampling as for compaction and shear resistance measurements.

One 600 ml beaker was labeled for each sample to be analyzed using pencil and non-volatile ink. Beakers were pre-dried for two hours in a gravity convection scientific oven calibrated at 105ºC. The tare weight of each beaker was recorded to the nearest 0.01g. Sand samples were then randomly selected for analysis. The entire sample of known volume was placed into its corresponding beaker. Care was used to transfer all of the sand, to keep spilling or leaving sand in the sampling bag to a minimum. The weight of the beaker and wet sample was recorded to the nearest 0.01g. Each beaker was covered with Aluminum foil to prevent exposure to open air. All samples were dried for 16 hours at 105ºC. Samples were allowed to cool without exposure to open air. The weight of the beaker and dry sample was recorded to the nearest 0.01g. Bulk density (g/cm3) was determined by dividing the weight of dry sand by the volume inside the core sampler. Water content was also obtained by dividing the volume of water in each sample (assuming 1g/mL as the density of water) by the total volume of that sample. Each sample was returned to its original Ziploc bag and sealed in an un-iced cooler for storage and transport.

Grain Size Distribution and Soil Color

U.S. Fish and Wildlife Service requirements dictate that all fill material placed must be compatible with natural, undisturbed beach sand in the area being nourished. Grain size distribution must be similar such that it does not contain construction debris, rocks, or other foreign matter. Furthermore, fill material must not contain, on average, more than 10% silt and clay, which is defined as fine material passing the #200 (0.075 mm particle diameter) ASTM Standard Sieve; and must not contain, on average, more than 5% coarse gravel or cobbles, excluding shell material, that is retained by the #4 (4.75 mm) ASTM Standard Sieve (Mizzi 2005).

Dried samples collected for bulk density and water content analysis were transported to the University of Florida soil science laboratory in Gainesville, FL. All samples were analyzed on the basis of color and grain size distribution under laboratory conditions. ASTM standard mesh sieves of standard sizes #18 (1 mm), #35 (0.5 mm), #60 (0.25 mm), #140 (0.106 mm), and #325 (0.045 mm) were stacked in ascending order with a clean collecting pan on the bottom. A single sample was randomly selected for analysis. A subsample of approximately 100g was weighed and poured into the sieve stack. The lid was placed on the stack, and the unit was situated on a mechanical sieve shaker. The unit was shaken for 5 minutes using the timer on the sieve shaker. After removal from the mechanical sieve shaker, each sand fraction was weighed individually from top to bottom. Weights were recorded to the nearest 0.01g. Each sieve and the collecting pan were cleaned gently with a small brush between samples. The mass of soil in all sieve fractions was compared to the mass of the entire sample before sieving for mass balance. For our purposes, the proportion of fine grains was considered that which passed through the smallest #325 (0.045 mm) sieve, and the proportion of coarse grains was considered that which was retained in the largest #18 (1 mm) sieve. These sieve sizes were the closest that we were able to obtain to the #200 and #4 standard sizes.

Soil color was determined using a Munsell soil color book. A quarter-sized pinch of dry soil was deposited into the palm of the gloved hand of the laboratory assistant. Color charts were held over the sample under sunlight, and a match was identified. Chroma and value as well as the reference number of the color chart (the hue) were recorded. Using deionized water, the same sample was wet until glistening, and the process of comparing the sample to the chart was repeated on a wet basis.

Soil Data Analysis

Data for each of the physical properties measured were first assembled into a histogram and checked for overall normality and to make sure that there was not a large proportion of zeroes. All variables were checked for dependency or correlation with other variables, and no significant correlations were found among any of the sand properties measured. If the normality assumption was reasonable and there were not too many zero values in the data, a paired t-test was used for analysis. Compaction and shear resistance did not meet the normality assumption; therefore these properties were analyzed using a Wilcoxon Sign-Rank test. Soil color, a categorical variable, was analyzed using a chi-square distribution. Table 3-c outlines the normality assumption verification and test used for each variable measured. All statistical analyses were performed using the program JMP® 7.0.1.

Results and Discussion

In 2007, Navarre beach, which was nourished in 2006, and Pensacola beach, nourished in 2005, were more physically similar to their natural beach partners as compared to 2006 values (Table 3-4). This indicates recovery over time of these recently nourished beaches to a state that is physically more similar to the native beach. Navarre beach also experienced changes in physical properties over the course of the 2006 season, most likely a result of sand being added to the system (Table 3-5). Panama City beach, which was nourished in 2005, and Okaloosa Island, nourished in 2004, were less physically similar to their natural beach counterparts in 2007 than they were in 2006. Okaloosa Island had differences in grain size distribution and compaction in 2007 that were not seen in 2006, and Panama City beach had differences in bulk density in 2007 that were not observed the previous year. There may be many reasons for this variability in sand properties, which could be attributable to the dynamic nature of the beaches themselves, human actions such as beach driving, tilling, or heavy foot traffic, or other factors. Even on nonnourished beaches, high levels of variability can be present among years. Cape San Blas beaches, which have not been nourished, were only different with regard to sand compaction over the course of the 2007 season, yet these quickly eroding beaches were highly variable with regard to differences in their physical properties among years, as were Alligator Point and Bald Point, both of which have yet to be nourished. Although a fair amount of variability was observed, at least some of these beaches seem to be recovering over time to a state more similar to that of the natural beach.

Compaction and Shear Resistance

In 2006, overall sand compaction was significantly different in only one of the five pairs of natural versus nourished beaches for which the nourished beach actually was nourished in time for this study. Three of the five pairs of beaches exhibited significant differences in compaction in 2007. Alligator Point and Bald Point appear to have a high level of natural variation in sand compaction levels, as do the Cape San Blas beaches. Shear resistance, which was only measured in 2007, was different only for Navarre beach and Santa Rosa. Navarre beach was nourished the most recently of all beaches studied, with sand placement occurring in 2006 (Table 3-4). Compaction was significantly different on Navarre beach upon the second sampling event in 2006. The natural Cape San Blas beach showed significantly different overall compaction over the course of the 2007 season, but its not yet nourished counterpart did not. There was no significant change in shear resistance over the course of the 2007 season for either Cape San Blas beach (Table 3-5). Compaction and shear resistance provide useful but different information and should both be included in monitoring programs following a beach nourishment project.

Bulk Density and Water Content

Differences in bulk density and water content were highly variable among all beach pairs during both study years (Table 3-4). Over the course of the 2006 and 2007 seasons respectively, bulk density was not found to be significantly different on any of the beaches that were sampled multiple times. Water content was significantly different on Navarre beach during the second round of sampling in 2006, but both Cape San Blas beaches showed no significant difference in water content between sampling events in 2007 (Table 3-5). Because water content is highly variable and depends on many factors including rainfall, tide, and time of day, it may not be the most useful indicator of the physical compatibility of sand on natural versus nourished beaches. However, results of a discriminant analysis (below) indicate that it may be an important contributing factor to measure. Bulk density is a property worthy of consideration because its measurements are less dependent upon daily fluctuations in ambient weather conditions.

Grain Size Distribution and Soil Color

No significant differences were found in soil color on any of the beach pairs that we studied. The proportion of fine grains was significantly different on Navarre beach as compared to Santa Rosa beach in 2006, but no significant difference was found in the proportion of fine grains on these beaches in 2007. Significant differences in the proportion of coarse grains were seen on Navarre beach versus Santa Rosa during both years of this study. There was no difference in the proportion of fine and coarse grains for either year on the two pairs of beaches for which the nourished counterparts were not nourished by the time of this study (Table 3-4). The proportion of fine and coarse grains was significantly different upon the second round of sampling in 2006 on Navarre beach. Cape San Blas beaches experienced no significant change in the proportion of fine or coarse grains over the course of the 2007 season (Table 3-5). Figure 3-4 displays the grain size distribution graphically for all beaches studied during both years, excluding Alligator Point, Cape San Blas, and their natural beach counterparts. Table 3-13 gives average grain size distribution and soil color values for all natural beaches, all nourished beaches, and all beaches during both years. Cape San Blas beach, Alligator Point beach, and their natural beach counterparts were excluded from table 3-13 because these beaches have not yet been nourished. Mean grain size was between 0.5mm and 0.25mm for all beaches, and neither the natural nor the nourished beaches had a high proportion of extremely coarse or extremely fine sand grains. The overall average color values for all beaches were 10Yellow-Red hue, 7.95 value, and 1.04 chroma in dry sand, and 10Yellow-Red hue, 6.66 value, and 1.36 chroma in wet sand. Florida has legal guidelines concerning the color of sediment placed on a nourished beach. According to our findings, these guidelines are doing their job of ensuring that sand placed on nourished beaches in northwest Florida is the same color as the natural beach sand. Grain size distribution, particularly the proportion of coarse and fine grains on a beach, should be measured in future monitoring studies following beach nourishment projects.

Discriminant Analysis

Results of a discriminant analysis performed using bulk density, water content, and grain size distribution (proportion of fine and coarse) as Y covariates and Nourished (Yes or No) as the X category resulted in a 24.7% misclassification. The Canonical plot (Figure 3-3) displays nonoverlapping normal 50% contours for Y (nourished) versus N (non-nourished) using these properties. Because using only these properties yielded results similar in accuracy to results obtained using all properties measured (23.6% misclassification), we conclude that of the properties we measured, bulk density, water content, and grain size distribution are the most important indicators of a nourished beach. Cape San Blas beaches, Alligator Point, and Bald Point were excluded from this analysis because these pairs of beaches have not yet been nourished (Table 3-2).

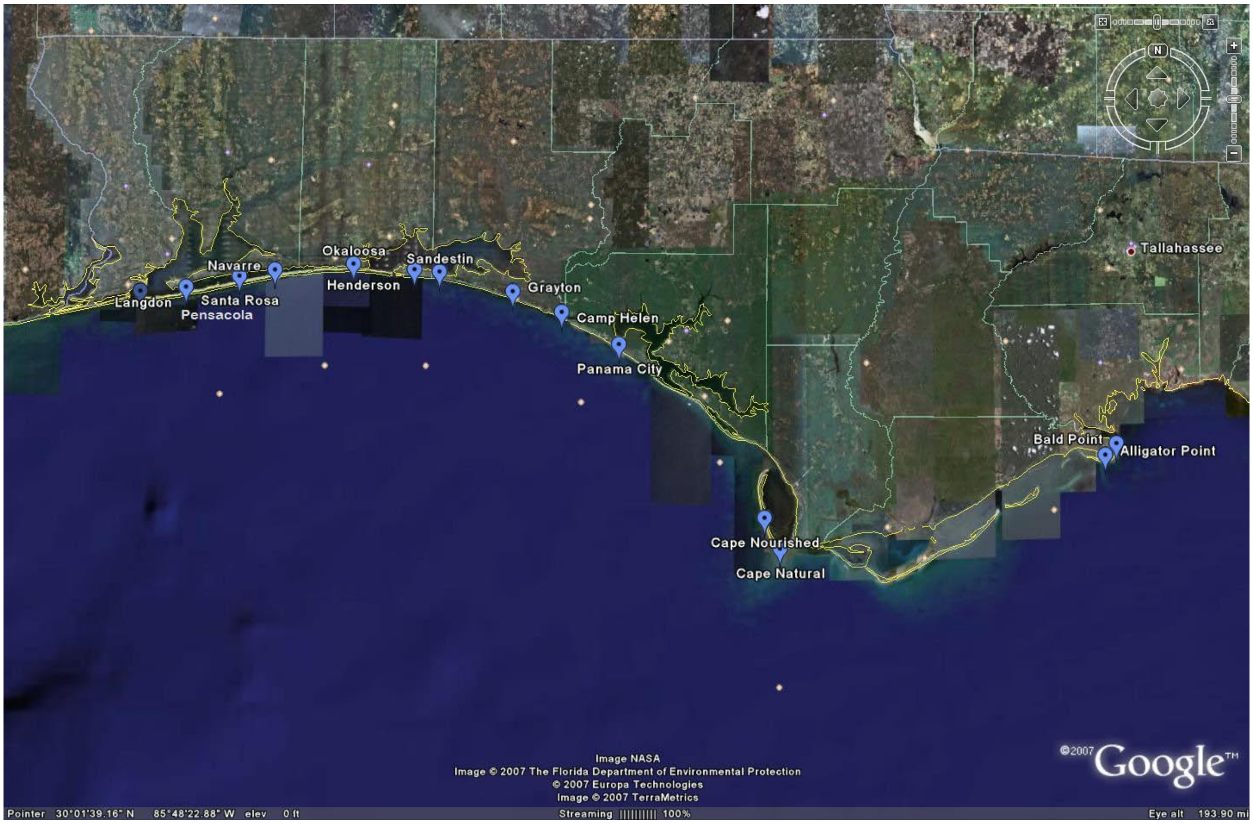


Figure 3-1. Map of sampling locations along the Florida panhandle.

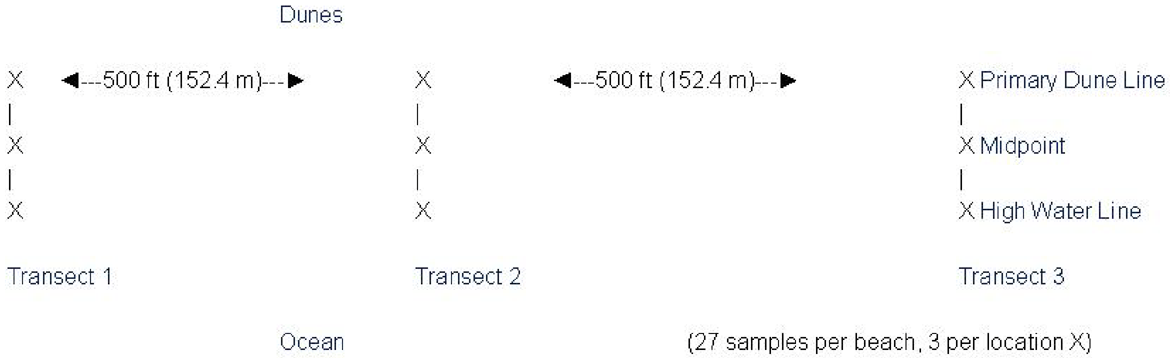


Figure 3-2. Sampling regime for core sand sampling, shear resistance, and penetrometer readings.

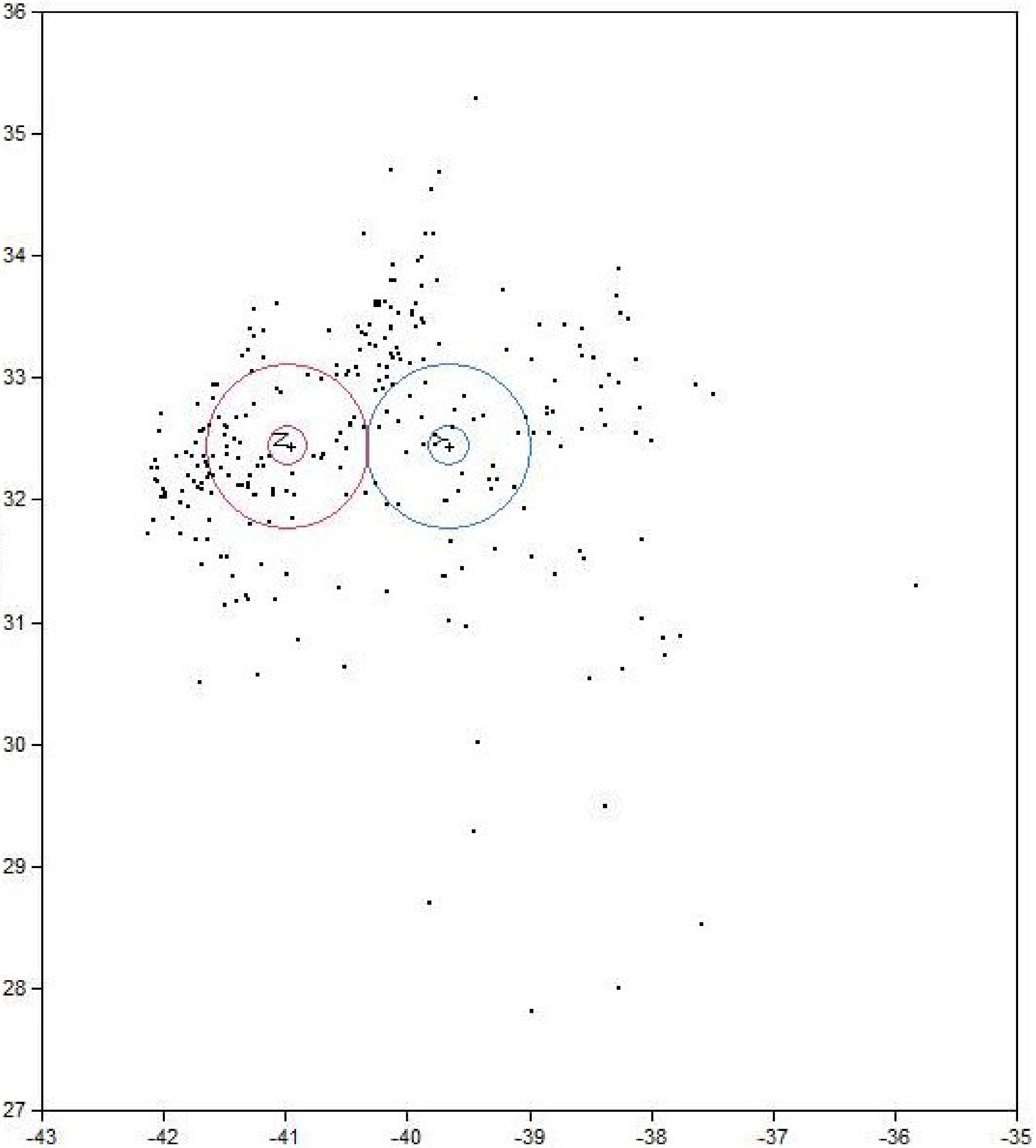


Figure 3-3. Canonical plot display of discriminant analysis results including normal 50% contours for nourished (Y) versus non-nourished (N).

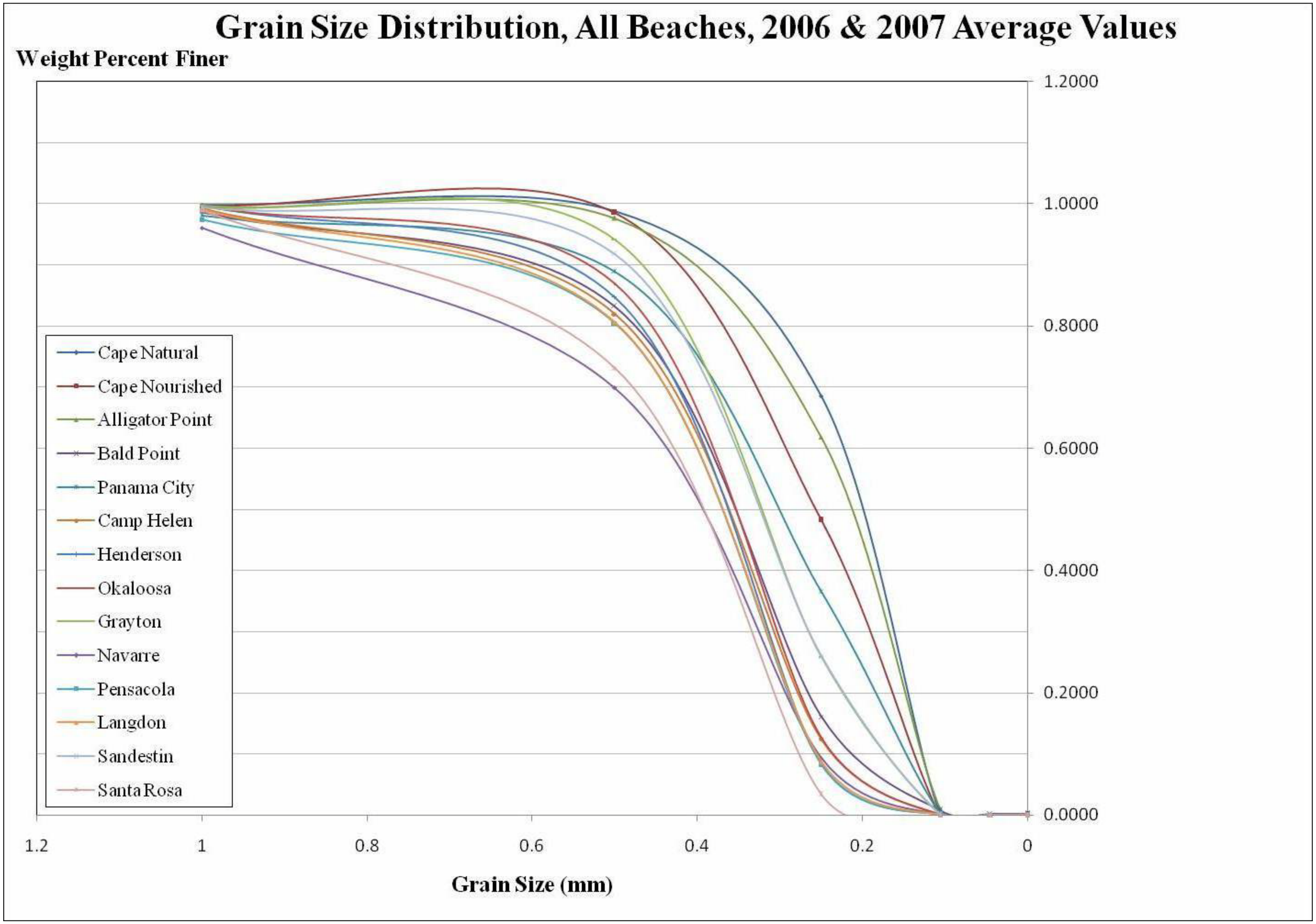


Figure 3-4. Graph of grain size distribution for all beaches, 2006 and 2007.

Table 3-1. Sampling locations of corresponding nourished and natural beaches included in this study.

Nourished Beach	Corresponding Natural Beach	County (Florida)
Alligator Pointe	Bald Pointe	Franklin
Cape San Blas (near State Park)	Cape San Blas (near lighthouse)	Gulf
Panama City Beach	Camp Helen State Park	Bay
Okaloosa Island	Henderson Beach State Park	Okaloosa
Sandestin Development Beaches	Grayton Beach State Park	Walton
Pensacola Beach	Langdon Beach	Escambia
Navarre Beach	Santa Rosa Island Authority	Santa Rosa

Table 3-2. Timing and method of nourishment of nourished beaches included in this study.

Nourished Beach	Year(s) of Nourishment	Nourishment Method
Alligator Pointe	N/A, Future nourishment plans exist	Dredge
Cape San Blas (near State Park)	N/A, Future nourishment plans exist (May 2008) Private groin bags (unpermitted) after Hurricane Ivan	Dredge, Bags
Panama City Beach	1976, 1982, 1984, 1986, 1988, 1996, 1998, 2004, 2005	Dredge
Okaloosa Island	2004	Dredge
Sandestin Development Beaches	1986, 1987, 1988	Dredge
Pensacola Beach	1986, 2003, 2005	Dredge
Navarre Beach	2006	Dredge

Table 3-3. Selection of statistical tests for comparing physical properties of sand on natural versus nourished beaches.

Physical Property of Soil	Normality Assumption Reasonable?	Test Selected for Comparison
Compaction	No, left skewed	Wilcoxon Sign-Rank Test
Bulk Density	Yes	Paired t-test
Water Content	Yes	Paired t-test
Prop. Fine Grains	Yes	Paired t-test
Prop. Coarse Grains	Yes	Paired t-test
Shear Resistance	No, too many zeroes	Wilcoxon Sign-Rank Test
Soil Color	N/A, categorical variable	Chi-Square

Table 3-4. Differences in physical properties of sand on pairs of natural and nourished beaches.

Physical Property of Soil	Beach Pairs Compared						
	Navarre*	Pensacola*	Panama City*	Okaloosa*	Sandestin*	Cape*	Alligator Point*
2006	Santa Rosa	Langdon	Camp Helen	Henderson	Grayton	Cape	Bald Point
Compaction	NS	NS	**	NS	NS	*	**
Bulk Density	*	**	NS	NS	**	NS	NS
Water Content	*	*	NS	*	**	**	**
Prop. Fine Grains	*	NS	NS	NS	NS	NS	NS
Prop. Coarse Grains	**	*	NS	NS	NS	NS	*
Soil Color	NS	NS	NS	NS	NS	NS	NS
2007							
Compaction	NS	*	**	**	NS	**	**
Bulk Density	*	NS	*	NS	**	**	*
Water Content	**	NS	NS	**	NS	**	**
Prop. Fine Grains	NS	NS	NS	*	NS	NS	NS
Prop. Coarse Grains	**	NS	NS	*	**	NS	NS
Soil Color	NS	NS	NS	NS	NS	NS	NS
Shear Resistance	*	NS	NS	NS	NS	**	**
*Year of Last Nourishment	2006	2005	2005	2004	1988	Future Plans	Future Plans

* indicates p<0.05, ** indicates p<0.01, NS indicates no significant difference.

Table 3-5. Differences in physical properties of sand on the same beach over the course of a season.

Beach	Navarre Beach	Cape (Natural)	Cape (Not Yet Nourished)
Compaction	**	**	NS
Bulk Density	NS	NS	NS
Water Content	**	NS	NS
Prop. Fine Grains	**	NS	NS
Prop. Coarse Grains	**	NS	NS
Soil Color	NS	NS	NS
Shear Resistance	N/A	NS	NS
Sampling Dates	7/10/06, 9/29/06	5/10/07, 8/12/07	5/11/07, 8/12/07

* indicates $p<0.05$, ** indicates $p<0.01$, NS indicates no significant difference.

Table 3-6. Mean color results for northwest Florida beaches in 2006.

Mean Color Values 2006				
Beach	Value (Dry)	Chroma (Dry)	Value (Wet)	Chroma (Wet)
Cape Natural	7.85	1.19	5.89	2.07
Cape Nourished	7.96	1.00	6.85	1.96
Alligator Point	8.00	2.00	6.88	2.31
Bald Point	7.81	1.67	6.67	2.30
Panama City	8.00	1.30	6.85	2.33
Camp Helen	8.00	1.07	7.00	1.52
Henderson	8.00	1.00	7.00	1.48
Okaloosa	8.00	1.00	7.00	1.19
Grayton	7.59	1.04	5.74	1.11
Navarre	8.00	1.00	7.00	1.93
Pensacola	8.00	1.00	7.00	1.85
Langdon	8.00	1.00	6.96	1.19
Sandestin	8.00	1.04	7.00	1.56
Santa Rosa	8.00	1.07	6.93	1.19

*Munsell Color Book, 10 YR Chart

Table 3-7. Mean color results for northwest Florida beaches in 2007.

Mean Color Values 2007				
Beach	Value (Dry)	Chroma (Dry)	Value (Wet)	Chroma (Wet)
Cape Natural	7.92	1.08	6.00	1.33
Cape Nourished	7.85	1.07	5.89	1.33
Alligator Point	8.00	1.22	6.00	1.85
Bald Point	7.59	1.96	5.81	2.96
Panama City	7.81	1.15	6.00	1.81
Camp Helen	8.00	1.00	6.15	1.07
Henderson	8.00	1.00	6.89	1.00
Okaloosa	8.00	1.00	6.89	1.00
Grayton	7.56	1.00	5.74	1.00
Navarre	8.00	1.00	6.59	1.44
Pensacola	8.00	1.00	6.63	1.15
Langdon	8.00	1.00	7.00	1.00
Sandestin	8.00	1.00	6.33	1.11
Santa Rosa	7.96	1.11	6.41	1.26

Table 3-8. Mean grain size results (% Passing) of each sieve size measured for northwest Florida beaches in 2006.

2006 Grain Size (average % Passing for each sieve size)						
Beach	no. 18	no.35	no.60	no.140	no.325	pan
Cape Natural	0.9946	0.9833	0.7101	0.0032	0.0003	0.0014
Cape Nourished	0.9979	0.9920	0.4857	0.0009	0.0001	0.0012
Alligator Point	0.9951	0.9762	0.6154	0.0130	0.0001	0.0010
Bald Point	0.9834	0.8028	0.1396	0.0080	0.0024	0.0021
Panama City	0.9842	0.8934	0.3564	0.0034	0.0003	0.0014
Camp Helen	0.9911	0.8265	0.1398	0.0003	0.0000	0.0012
Henderson	0.9952	0.8038	0.0716	0.0002	0.0000	0.0015
Okaloosa	0.9959	0.8511	0.1236	0.0002	0.0000	0.0019
Grayton	0.9965	0.9329	0.2981	0.0020	0.0000	0.0010
Navarre	0.9557	0.7171	0.1212	0.0013	0.0003	0.0019
Pensacola	0.9713	0.7891	0.0849	0.0008	0.0002	0.0011
Langdon	0.9920	0.8330	0.1011	0.0002	0.0000	0.0010
Sandestin	0.9942	0.9148	0.2729	0.0008	0.0001	0.0009
Santa Rosa	0.9920	0.7315	0.0317	0.0002	0.0001	0.0012

Table 3-9. Mean grain size results (% Passing) of each sieve size measured for northwest Florida beaches in 2007.

2007 Grain Size (average % Passing for each sieve size)						
Beach	no. 18	no.35	no.60	no.140	no.325	pan
Cape Natural	1.0009	0.9908	0.6602	0.0025	0.0001	-0.0023
Cape Nourished	0.9944	0.9774	0.4786	0.0012	0.0002	0.0002
Alligator Point	0.9913	0.9758	0.6195	0.0084	0.0000	0.0010
Bald Point	0.9901	0.8610	0.1820	0.0084	0.0023	0.0019
Panama City	0.9764	0.8850	0.3746	0.0043	0.0002	0.0015
Camp Helen	0.9925	0.8119	0.1079	0.0002	0.0000	0.0010
Henderson	1.0003	0.8909	0.0950	0.0001	0.0000	-0.0007
Okaloosa	0.9972	0.8861	0.1293	0.0000	0.0000	0.0010
Grayton	0.9987	0.9509	0.2205	0.0009	0.0000	0.0009
Navarre	0.9651	0.6804	0.0653	0.0005	0.0002	0.0002
Pensacola	0.9770	0.8188	0.0801	0.0005	0.0002	0.0011
Langdon	0.9883	0.7784	0.0738	0.0000	0.0000	0.0000
Sandestin	0.9937	0.9198	0.2465	0.0005	0.0001	0.0011
Santa Rosa	0.9857	0.7297	0.0358	0.0003	0.0001	0.0013

Table 3-10. ASTM standard sieve opening sizes (cm) for sieves used in this study.

ASTM Sieve Number	Size of Opening (cm)
18	0.1
35	0.05
60	0.025
140	0.0106
325	0.0045

Table 3-11. Average bulk density (g/cm^3), water content, and compaction (Newtons) results for northwest Florida beaches in 2006.

2006 Average Values			
Beach	Bulk Density	Water Content	Compaction
Cape Natural	1.62	0.20	290.19
CapeNourished	1.60	0.13	187.94
Alligator Point	1.60	0.23	167.73
Bald Point	1.62	0.09	67.21
Panama City	1.61	0.06	108.29
Camp Helen	1.60	0.06	75.67
Henderson	1.61	0.04	62.75
Okaloosa	1.61	0.05	71.52
Grayton	1.72	0.13	89.80
Navarre	1.65	0.04	104.69
Pensacola	1.63	0.04	101.87
Langdon	1.60	0.06	61.99
Sandestin	1.51	0.77	98.58
Santa Rosa	1.62	0.05	67.38

Table 3-12. Average bulk density (g/cm^3), water content, compaction (Newtons), and shear resistance results (Newton-meters) for northwest Florida beaches in 2007.

2007 Average Values				
Beach	Bulk Density	Water Content	Compaction	Shear Resistance
Cape Natural	1.49	0.14	167.37	17.41
Cape Nourished	1.60	0.09	76.31	11.45
Alligator Point	1.67	0.14	146.50	19.27
Bald Point	1.69	0.07	70.19	10.29
Panama City	1.65	0.06	105.20	11.00
Camp Helen	1.63	0.07	73.42	10.95
Henderson	1.63	0.05	58.69	11.21
Okaloosa	1.63	0.64	25.09	9.71
Grayton	1.70	0.63	70.21	12.81
Navarre	1.64	0.64	40.59	14.85
Pensacola	1.65	0.63	51.16	11.81
Langdon	1.63	0.64	32.21	11.97
Sandestin	1.67	0.64	65.50	14.51
Santa Rosa	1.67	0.04	53.88	11.33

Table 3-13. Average values of all sand properties measured on natural, nourished, and all beaches.

2006 and 2007	Average Values			
	Bulk Density	Water Content	Compaction	Shear Resistance
All Natural	1.64	0.18	64.60	11.65
All Nourished	1.62	0.36	77.25	12.38
All beaches	1.63	0.27	70.93	12.02
	Color			
	Value (Dry)	Chroma (Dry)	Value (Wet)	Chroma (Wet)
All Natural	7.91	1.03	6.58	1.18
All Nourished	7.98	1.05	6.73	1.54
All beaches	7.95	1.04	6.66	1.36
	Grain Size (average % Passing for each sieve size)			
	1mm	0.5mm	0.25mm	0.106mm and finer
All Natural	0.99	0.83	0.12	0.00
All Nourished	0.98	0.84	0.19	0.00
All beaches	0.99	0.83	0.15	0.00

*Excludes Alligator Point, Bald Point, and Cape San Blas Beaches, which have not yet been nourished.

CHAPTER 4
EFFECTS OF DIFFERENCES IN PHYSICAL PROPERTIES OF SAND ON LOGGERHEAD (*CARETTA CARETTA*) SEA TURTLE NESTING IN NORTHWEST FLORIDA

Introduction

In oviparous species, the habitat in which eggs are deposited greatly influences the survival of the offspring and therefore could have significant consequences for the reproductive success of the adult (MARTIN, 1988, HAYS AND SPEAKMAN ,1993). Marine turtles evolved secondarily into an aquatic existence and have unique adaptations pertaining to the species-habitat relationship (EHRHART, 1998). All marine turtles possess modified limbs or flippers that work nicely for swimming but are poorly suited for terrestrial locomotion; but because marine turtles have retained an oviparous reproductive strategy, their survival hinges on their ability to nest terrestrially (PRITCHARD, 1997). Nest site selection is an adaptive compromise between the cost of searching and the reproductive benefits of selecting a successful site for egg incubation (WOOD and BJORNDAL, 2000).

Tagging studies reveal that most nesting female loggerheads come back to the same area in successive nesting seasons and that males and females return to resident foraging areas between reproductive migrations (LIMPUS *et al.*, 1992). However, adult site fidelity may not require natal homing. Neophyte nesting females may follow experienced breeders to a nesting beach and focus on that area for subsequent nesting efforts, a behavior known as social facilitation (OWENS *et al.*, 1982). Using social facilitation, the nesting beaches in a particular region would be linked by gene flow, whereas using natural homing, individual nesting colonies would be genetically isolated by homing behavior (BOLTEN and WITHERINGTON, 2003).

Reproductively active female turtles tend to exhibit nest site fidelity for beaches that over evolutionary time have possessed characteristics conducive to successful nesting (CARR, 1986, WITHERINGTON, 1986, BOWEN *et al.*, 1992, WEISHAMPEL *et al.*, 2003). This behavior results in high reproductive success and offspring survival in contrast to random beach selection (BJORNDAL and BOLTEN, 1992, CRAIN *et al.*, 1995). However, the evolution of a female's ability to select or be more drawn to beaches on which their eggs would stand a better chance of survival has not been demonstrated. Turtles sometimes nest in media that produce zero hatching success and contain sands that are less than optimal for clutch survival (MORTIMER, 1990). Therefore, coastal managers should be mindful of the physical characteristics of fill material used in beach nourishment projects.

Haplotype frequencies of mitochondrial DNA (mtDNA) have been used to determine how precise natal homing behavior is in loggerhead turtles. Pearce found that most adjacent beaches do not have significantly different mtDNA haplotype frequencies (2001). However, study results did resolve three independent clusters of nesting beaches corresponding to the Florida panhandle (Gulf of Mexico), southern Florida, and northeast Florida, with additional management units indicated for the Dry Tortugas and possibly Volusia County (north of Cape Canaveral). Pearce suggests that population partitions are evident in loggerhead nesting habitats separated by 100+ km of inappropriate nesting habitat, providing an approximate benchmark for natal site fidelity (2001). Nesting habitats are most likely ephemeral over an evolutionary timescale, continually arising and disappearing due to changes in the physical environment (sea level, geography, and beach characteristics), global climate (glacial intervals), and biotic environment (nest predation or competition for nesting space). Because rookeries are transient over evolutionary time, absolute natal homing would be a formula for extinction (BOLTEN and WITHERINGTON, 2003).

A large proportion of sea turtles nests occur on nourished beaches in the United States (NELSON and Dickerson, 1989), therefore, consideration and careful monitoring in regards to the effects of nourishment practices on these threatened and endangered species is critical to beach restoration (CRAIN *et al.*, 1995). Typically, in the first season following a nourishment episode, loggerhead sea turtle (Caretta caretta) nesting success is adversely affected, but a return to near average levels is usually observed by the second or third season. Nesting success on nourished and natural beaches is more comparable when the physical characteristics of the beach become similar (STEINITZ *et al.*, 1998). Hardened sediment can prevent a female sea turtle from successfully excavating a nest chamber or result in a poorly constructed nest cavity. If nesting does occur in hardened sediment, embryonic development within a nourished nest cavity can be adversely affected by insufficient oxygen diffusion and variation in moisture content levels inside the egg clutch (ACKERMAN, 1980, MORTIMER, 1990, ACKERMAN *et al.*, 1992). The use of physically compatible fill material is necessary to minimize the detrimental effects of beach nourishment on sea turtles and their hatchlings.

Beach compaction due to the use of fine-grained sand may make it difficult for a female to excavate a nest. Conversely, sand that is too coarse could cause the nest to collapse during excavation (MORTIMER, 1990). Another important factor relevant to nesting success is the temperature of the sand in which the eggs incubate. The sex of turtle hatchlings is temperature dependent, with cooler temperatures producing a higher proportion of males and warmer temperatures producing a higher proportion of females, and the temperature of the incubation environment is very dependent upon the color of the sediment (MROSOVSKY and YNTEMA, 1980). Consequently, a nourishment project that utilizes sediment that does not match the natural color of a particular beach could alter the sex ratio of the hatchlings, which could potentially impact the future breeding success of already threatened sea turtle species (MILTON *et al.*, 1997).

Homing by females designates each nesting colony as a demographically independent unit having a distinct sex ratio, age class structure, survivorship, and other demographic characteristics. Male-mediated gene flow does not modify the status of nesting populations as independent management units. In terms of management implications, it is helpful to consider the extreme situations: if all females at a nesting colony were killed, mtDNA data indicate that the nesting colony would die away. If all breeding males in an area were killed, nDNA data indicate that other males would quickly fill the void. Therefore, nesting populations are still the fundamental unit of sea turtle management (BOLTEN and WITHERINGTON, 2003).

Florida's panhandle has low levels of loggerhead nesting relative to other areas within the state, but these turtles are important in terms of conservation and management because they are genetically distinct contributors to the overall Florida loggerhead population as mentioned above. Taken together, data from mitochondrial DNA (mtDNA) and data from nuclear DNA (nDNA) indicate that females show site fidelity for a particular nesting region in the southeast United States, while males supply an avenue of gene flow between nesting locations (PEARCE, 2001). Male-mediated gene flow facilitates strong connections between regional nesting colonies throughout the southeastern United States, passing on nuclear genes that mediate disease resistance, response to environmental challenges, and thousands of other key survival traits. Because of this gene flow, small nesting colonies such as those in the Florida panhandle do not suffer the bottleneck effects of reduced genetic diversity (PEARCE, 2001). This puts to rest concerns about inbreeding and any corresponding loss of genetic diversity for this population (BOLTEN and WITHERINGTON, 2003).

The objective of this study was to determine whether differences existed in physical properties of sand from natural versus nourished beaches, and if any differences observed had an impact on loggerhead sea turtle nesting in northwest Florida.

Methods

In summer 2006, 27 core soil samples per beach were taken on seven pairs of natural and nourished beaches along the Florida Panhandle. Compaction measurements were also taken at each sampling site using a cone penetrometer. Each core sample was dried for 16 hours at 105°C in a gravity convection oven. Bulk density and water content of samples were calculated. Samples were transported to Gainesville, FL in an un-iced cooler where they were analyzed on the basis of color (wet and dry basis) and grain size distribution under laboratory conditions. In summer 2007, methods of core sampling, compaction reading, and other analyses were repeated on all beaches. In addition, shear resistance measurements were taken alongside compaction readings using a digital torque wrench attached to a 2.5 times magnified shear vane developed for this study which was rotated over a 90 degree angle.

Data on loggerhead sea turtle nest counts, nesting density, false crawls, and hatching success on the study beaches were obtained from the Florida Marine Research Institute and examined for patterns that could be related to sand quality and nourishment status. There was insufficient data for statistical analysis of the sea turtle data, but observations were made about general trends. Two measures of nesting success were used. The first was nesting density, which was calculated as the number of nests per kilometer of beach. The second was false crawl to nest ratio, which was the number of false crawls divided by the number of nests. Two measures of hatching success were also examined. Hatching success was calculated as the number of eggs that hatched divided by the total number of eggs in the nest. Emerging success was calculated by subtracting the number of turtles dead in the nest from the number that hatched before dividing by the total number of eggs in the nest.

Results and Discussion

Differences in physical properties of sand on pairs of natural and nourished beaches were discussed in Chapter 3 and are summarized in Table 3-4. Table 4-1 shows the 2002 to 2006 loggerhead sea turtle nesting density for all pairs of beaches studied. Figure 4-3 displays these results graphically. Although nesting density was slightly lower on Panama City beach during the year of and the year following nourishment, other beaches did not experience this trend. Also, the lower levels observed on Panama City beach following the nourishment were not drastically lower than in the years preceding the nourishment. Table 4-2 gives nesting counts for all beach pairs studied between 2002 and 2006. Data dating back from 2002 indicate that 2006 was not a significantly low “off” year, but that it was instead in keeping with normal nesting levels for these Florida panhandle beaches. The ratio of false crawls to nests is given in Table 4-3 and in Figure 4-4. False crawl to nest ratio was higher on Panama City beach during its nourishment year, but not on other beaches during their nourishment years. The highest false crawl to nest ratio observed was seen on Langdon beach, a natural, dark, undeveloped beach where turtles were least likely to be disturbed by human causes. Because of the high and unexplained variability in false crawl to nest ratios, examining false crawls may not be the best indicator of sea turtle nesting success on the beaches of northwest Florida. Hatching success is displayed in Table 4-4 and in Figure 4-1. Lower hatching success was observed on Pensacola and Panama City beaches during 2005, their nourishment year, but not on Okaloosa Island during 2004, its nourishment year. Hatching success varied widely among natural beaches, particularly where nesting counts were very low, but this parameter is important to measure following a beach nourishment project to ensure that nourishment efforts are not creating a poor incubation environment. Emerging success, which is displayed in Table 4-4 and in Figure 4-2, was similar to hatching success on all beaches studied. There was also a similar level of variability among the natural beaches. Emerging success did not appear to be severely lower than hatching success on any beach; therefore, beach nourishment does not appear to be contributing to a lower emerging success relative to hatching success on the beaches studied.

Table 4-1. Nesting Density of loggerhead sea turtles in northwest Florida from 2002 to 2006.

Loggerhead Sea Turtle Nesting Density (# of nests per km of beach)					
Nourished*/Natural	2002	2003	2004	2005	2006
Navarre*/Santa Rosa	No Data/0.38	No Data/1.35	0.00/0.96	0.00/0.58	0.00/0.19
Pensacola*/Langdon	0.30/0.34	0.44/0.81	0.52/0.58	0.67/0.26	0.52/0.45
Panama City*/Camp Helen	0.76/No Data	0.36/0.83	0.97/0.00	0.76/0.83	0.40/1.67
Okaloosa*/Henderson	0.07/0.00	0.59/0.45	0.37/0.91	0.74/0.91	0.29/0.45
Sandestin*/Grayton	0.88/0.79	0.93/1.05	0.56/1.05	0.50/1.32	0.50/0.00
Cape*/Cape	1.33/6.46	2.29/12.29	1.24/10.21	1.14/3.13	0.86/5.00
Alligator Point*/Bald Point	1.57/No Data	3.57/1.67	2.71/0.83	1.29/0.00	0.14/1.04

Table 4-2. Nest counts of loggerhead sea turtles in northwest Florida from 2002 to 2006.

Loggerhead Sea Turtle Nesting Counts (# of nests)					
Nourished*/Natural	2002	2003	2004	2005	2006
Navarre*/Santa Rosa	No Data/2	No Data/7	0/5	0/3	0/1
Pensacola*/Langdon	4/13	6/31	7/22	9/10	7/17
Panama City*/Camp Helen	21/No Data	10/1	27/0	21/1	11/2
Okaloosa*/Henderson	1/0	8/1	5/2	10/2	4/1
Sandestin*/Grayton	33/3	35/4	21/4	19/5	19/0
Cape*/Cape	14/31	24/59	13/49	12/15	9/24
Alligator Point*/Bald Point	11/No Data	25/8	19/4	9/0	1/5

Table 4-3. Ratio of false crawls to nests for loggerhead sea turtles in northwest Florida from 2002 to 2006.

Loggerhead Sea Turtle False Crawl/Nest Ratio (# of false crawls/# of nests)					
Nourished*/Natural	2002	2003	2004	2005	2006
Navarre*/Santa Rosa	No Data/0.50	No Data/0.14	0FC /0.40	1FC /2.00	0FC /0.00
Pensacola*/Langdon	0.25/0.69	1.00/1.10	0.71/0.59	0.67/4.40	1.57/3.24
Panama City*/Camp Helen	0.62/No Data	1.50/0.00	0.30/ 0FC	1.57/0.00	0.64/0.00
Okaloosa*/Henderson	2.00/ 0FC	0.75/0.00	0.40/0.00	0.80/0.50	0.25/2.00
Sandestin*/Grayton	0.64/0.33	0.63/0.50	0.52/0.75	1.68/0.40	0.79/ 2FC
Cape*/Cape	1.43/2.19	1.21/1.49	1.15/1.39	0.75/3.80	1.78/2.96
Alligator Point*/Bald Point	1.55/No Data	2.64/0.63	0.95/9.75	2.44/ 7FC	4.00/5.00

Table 4-4. Hatching success and emerging success of loggerhead sea turtles in northwest Florida from 2002 to 2005.

Beach	2002 Hatching Success	2002 Emerging Success	2003 Hatching Success	2003 Emerging Success	2004 Hatching Success	2004 Emerging Success	2005 Hatching Success	2005 Emerging Success	*Year of Last Nourishment
Navarre*	No Data	No Data	No Data	No Data	No Nests	No Nests	No Nests	No Nests	2006
Santa Rosa	0.93	0.93	0.88	0.88	0.63	0.62	0.95	0.93	
Pensacola*	0.81	0.81	0.82	0.82	0.80	0.80	0.66	0.66	2005
Langdon	0.65	0.65	0.76	0.76	0.71	0.71	0.53	0.53	
Panama City*	0.83	0.82	0.54	0.53	0.68	0.68	0.16	0.15	2005
Camp Helen	No Data	No Data	No Data	No Data	No Nests	No Nests	0.00	0.00	
Okaloosa*	No Data	No Data	0.68	0.68	0.96	0.96	0.37	0.37	2004
Henderson Beach	No Nests	No Nests	0.01	0.01	0.90	0.90	0.24	0.24	
Sandestin*	0.72	0.71	0.65	0.63	0.69	0.68	0.45	0.42	1988
Grayton	0.84	0.83	0.14	0.14	0.45	0.44	No Data	No Data	
Cape Nourished*	0.68	0.67	0.61	0.60	0.75	0.75	0.48	0.48	Future Plans
CapeNatural	0.39	0.36	0.58	0.57	0.33	0.27	No Data	No Data	
Alligator Point*	0.71	0.63	0.63	0.62	0.64	0.64	No Data	No Data	Future Plans
Bald Point	No Data	No Data	0.78	0.72	0.86	0.86	No Nests	No Nests	

CHAPTER 5
DISCUSSION AND CONCLUSIONS

Because our findings suggest that sand compaction is not linearly correlated with shear resistance, we conclude that measuring shear resistance as a separate entity from beach compaction is critical. Measuring shear resistance provides additional information about the physical condition of sand placed on a beach during nourishment and may offer valuable insights from a sea turtle conservation management perspective. In order for the shear vane device to be implemented as a management tool following beach nourishment projects, future studies should be conducted. Studies should focus on higher density nesting beaches with a goal of obtaining a tolerable range of shear resistance levels for loggerhead sea turtles, both on the surface and at depth. If a tolerable range of shear resistance could be determined for nesting sea turtles on Florida beaches, guidelines could be established to promote a more suitable nesting habitat for sea turtles on nourished beaches.

Our shear vane device was a more useful tool at depth than on surface sand, particularly on nourished beaches, where surface readings registered a zero value 93% of the time. These results may be improved by using a range of different shear vane sizes and perhaps pairing them with more or less sensitive torque wrenches, depending on the size of the shear vane used. Using different sized torque wrenches and shear vanes may combat the problem of the lower detectability limit observed for shear resistance measurements in this study.

Overall, beach nourishment practices in northwest Florida seem to be compatible with loggerhead sea turtle nesting; and implementing shear resistance measurements as an additional parameter to examine following a beach nourishment project would provide useful information to coastal managers. Other properties measured including compaction, bulk density, grain size distribution, water content, and soil color, also provide useful information and should be included in management protocol following a beach nourishment project. Hatching success and emerging success seem to be good indicators of the suitability of the incubation environment for loggerhead sea turtles, while nesting density appears to be a more useful indicator of nesting success on a particular beach than does the false crawl to nest ratio.

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BIOGRAPHICAL SKETCH

As a child, Lori always had a deep appreciation for the beauty and uniqueness of the world's oceans. At age 12, she became a certified scuba diver with her dad, and over the years she has become passionate about conserving the underwater environment and its inhabitants. In 2004, Lori was a sea turtle intern for the Bald Head Island Conservancy in North Carolina. That same year, Dr. Dean Hesterberg, a soil scientist at N.C. State University, allowed her to work in his lab on an undergraduate research project and subsequently helped her develop a second project aimed at examining effects of beach nourishment on sea turtles. His efforts were probably the driving force behind Lori's desire to pursue a career in science. Lori received undergraduate degrees in biological sciences and botany from North Carolina State University in 2005 and began applying to graduate schools with the hope of landing a sea turtle project. Dr. Ray Carthy responded to her request and has provided outstanding mentoring and guidance throughout her tenure at the University of Florida. Upon graduation, Lori will be seeking employment in her field and hopes to make a positive difference in the future of our natural resources.