An Assessment Of Sea Turtle Nesting Behavior In Relation To Hurricane- And Restoration-induced Beach Morphodynamics

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AN ASSESSMENT OF SEA TURTLE NESTING BEHAVIOR IN RELATION TO HURRICANE- AND RESTORATION-INDUCED BEACH MORPHODYNAMICS

by

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ABSTRACT

Coastal habitats are highly dynamic and vulnerable to landscape-level disturbances such as storms and restoration projects. Along the east coast of Florida these areas are particularly valuable as they provide significant nesting habitat for two sea turtle species, the threatened loggerhead (*Caretta caretta*) and the endangered green turtle (*Chelonia mydas*). This coast was heavily impacted by three major hurricanes in 2004 and in some areas by large restoration projects in 2005. Recent remote sensing methods allow for broad evaluation of the shoreline and thus the ability to assess sea turtle nesting habitat at a landscape scale.

I collected nesting data for southern Brevard County, Florida from 1989 – 2005 and for Canaveral National Seashore, Florida from 1995 – 2005. I used LiDAR (Light Detection and Ranging) and IfSAR (Interferometric Synthetic Aperture Radar) remote sensing to map sea turtle nesting habitat in both areas following the 2004 hurricanes and any subsequent restoration. Canaveral National Seashore underwent no restoration while southern Brevard County received extensive restoration. Topographic variables (e.g., total sand volume, width, and slope) derived from the remote sensing data were compared across three time periods (pre-hurricane, post-hurricane, and recovery period) and I compared nesting success data from 2004 to 2005. I built regression models for 2004 and 2005 to determine which topographic features influenced loggerhead and green turtle nesting the most.

Green turtle nesting success declined from 2004 to 2005 only in highly restored areas while loggerhead nesting sucess declined throughout. Hurricanes caused a reduction in most of the topographic variables and restoration predominantly impacted aspects of the beach profile (e.g. slope and width). Loggerheads responded to profile characteristics (e.g. upper and lower beach slopes) though green turtles showed no consistent response to topography. The results indicate that both loggerheads and green turtles are sensitive to beach restoration, although loggerhead nesting is more influenced by beach morphology and green turtle nesting may be influenced more by other dune features such as vegetation cover.

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INTRODUCTION

In coastal habitats, landscape-level disturbances such as storm erosion or beach restoration alter the physical composition of the beach to which denizen species are sensitive thereby influencing their habitat use (Melvin et al. 1991; Snyder & Boss 2002; Pries et al. 2009). Beach erosion often reduces habitat availability following a storm (Pries et al. 2009) and restoration projects alter natural erosion and accretion processes, potentially degrading habitat suitability (Melvin et al. 1991). Sea turtles rely on specific beaches for nesting and therefore are particularly vulnerable to habitat alteration. Severe storm activity has been known to damage sea turtle nests via washouts, flooding or exposure, greatly decreasing reproductive success (Pike & Stiner 2007; Van Houtan & Bass 2007). Additionally, sea turtle nesting has been consistently shown to decrease during the nesting season following beach restoration projects (Steinitz et al. 1998; Rumbold et al. 2001; Brock et al. 2009) though factors that contribute to this decline are not well understood.

Female sea turtles typically nest biennially and lay several nests in a season (Carr & Carr 1970; Miller 1997). They exhibit high nest site fidelity (Carr & Carr 1972) and nest placement frequently displays spatial consistency throughout the season (Weishampel et al. 2006) and from year to year (Weishampel et al. 2003). Often females emerge from the ocean and then return without nesting (known as a non-nesting emergence or improperly as a false crawl). These aborted nesting attempts have generally been attributed to unfavorable nesting conditions (Johnson et al. 1996; Brock et al. 2009) and females usually return to a nearby section of beach by the following night to nest (Miller 1997). Because of this tendency, the nesting success of a particular area (defined as the ratio of nests to the total number of emergences) is often used as a way to gauge reproduction in an area from year to year. Many of the characteristics that influence nest site selection are also conducive to high hatching success of the eggs (Wood & Bjorndal 2000; Karavas et al. 2005; Foley et al. 2006), thus nesting success and reproductive (hatching) success are each affected by sea turtle nesting behavior. Fluctuations in the number of nests laid each year (particularly for green turtles, see Weishampel et al. 2003) cause nesting success to be a stable and reliable indicator of reproduction and make changes in nesting patterns more apparent. Throughout the state of Florida, the number of green turtle nests has increased consistently over the past decade (Florida Fish and Wildlife Conservation Commission 2009) while the number of loggerhead nests has declined (Witherington et al. 2009). Nesting success for both species, however, tends to remain relatively constant (Dodd 1988; Weishampel et al. 2003).

Several local factors have been shown to affect nesting behavior including sand grain size and moisture content (Wood & Bjorndal 2000; Karavas et al. 2005). Though responses to landscape morphodynamics have received less attention, it has been suggested that the shapes of beach profiles, including the slopes of the dune and foredune, may contribute to the selection of a nest site (Hays et al. 1995; Wood & Bjorndal 2000; Long et al. in press). Loggerheads have been shown to prefer moderately wide beaches, possibly because this provides nesting females with a greater selection of nest sites with favorable characteristics (Garmestani et al. 2000; Mazaris et al. 2006). Slope has also been suggested as an important factor in loggerhead nest-site selection, specifically the change in slopes or profile shapes between beach zones (i.e. from open beach to dune), as this may serve as an indicator of distance from the water (Wood & Bjorndal 2000; Long et al. in press). Morphological beach preferences of green turtles have not been well studied, but research has indicated that they too may be prompted to nest by the change in shape from the open beach to the dune (Hays et al. 1995).

Coastal ecosystems are naturally dynamic due to regular cycles of erosion and accretion. With the onset of hurricane or other severe storm activity, there is greater potential for exceptionally high levels of erosion (Zhang et al. 2002; Morton & Sallenger 2003; Zhang et al. 2005), a problem that has been exacerbated by rising sea levels in recent years (Galbraith et al. 2002; Dugan et al. 2008). This increased stress on coastal systems intensifies the pressure on coastal management agencies to both "protect" beachside properties and "restore" coastal habitat. Measures of shoreline protection may include artificial beach restoration or the building of hard armoring structures such as seawalls. Both methods of protection have been shown to affect the physical characteristics of the beach habitat, effectively altering ecosystem functionality. The presence of seawalls often leads to a reduction in diversity of macroinvertebrates as well as a reduction in available prey and habitat for shorebirds and seabirds (Dugan et al. 2008), while beach restoration can reduce horseshoe crab egg development (Avissar 2006). Because of the documented negative effects of hard armoring, methods of beach restoration have steadily increased in popularity (Jones & Mangun 2001; Speybroeck et al. 2006). These methods typically involve the acquisition of sand from inland quarries or by means of offshore dredging of sand, which is then redistributed on the beach. Some restoration projects focus on rebuilding the dune system only, while others place sand across the entire beach surface (often referred to as beach nourishment), effectively widening the beach. Following a restoration project, the beach may or may not fully mirror its pre-storm topography; however, it generally offers greater ecosystem functionality than the alternative critically eroded beach (Brock et al. 2009).

The rise in popularity of beach restoration as a method of coastal armoring has spurred numerous policy debates. Opponents of beach restoration note the fact that future storms or high tide events are likely to wash away the new sand placed on restored beaches, making restoration a waste of money (Jones & Mangun 2001). Furthermore, financing the project must often be achieved by charging fees for beach access (Kriesel et al. 2004). On the other hand, proponents cite the increase in property values and tourism income associated with the "pristine" look of the restored beach (Jones & Mangun 2001; Kriesel et al. 2004). Additionally, beachside property can be protected from erosion without having to build new structures on the beach. Despite the debate, beach restoration has become the most common method of coastal armoring used in the United States (Speybroeck et al. 2006).

Along the east coast of Florida, storm erosion occurs most notably during hurricane season (June through November) when frequent storm activity is common and occasionally in the winter months as a result of strong nor'easters. In 2004, the state experienced an unusually active hurricane season with four major hurricanes making landfall within six weeks. Three of these storms (Charley, Frances, and Jeanne) directly impacted the state's east coast, a highly important nesting beach for two species of sea turtle: the threatened loggerhead (*Caretta caretta*) and the endangered green turtle (*Chelonia mydas*).

Recently, airborne LiDAR (Light Detection and Ranging) and IfSAR (Interferometric Synthetic Aperture Radar) remote sensing systems have been applied to analyze the dynamics of dune and shoreline morphology due to their efficiency at sampling large areas with a high degree of accuracy (Woolard & Colby 2002; Sallenger et al. 2003; Dellepiane et al. 2004; Liu et al. 2007). LiDAR and IfSAR have been used to generate habitat maps for coastal flora (Goodale et al. 2007) and fauna (Sellars & Jolls 2007), as well as to assess hurricane-induced erosion (Zhang et al. 2005; Robertson et al. 2007), restoration projects (Gares et al. 2006) and shoreline responses to climate change (Brown 2006). For this study I used LiDAR and IfSAR remote sensing to determine how topographic changes resulting from the hurricanes in 2004 and subsequent restoration in early 2005 impacted loggerhead and green sea turtle nesting success along the central east coast of Florida. If sea turtles use beach topography as a cue during nest site selection, then landscape-level changes in topography due to severe storms or large-scale beach restoration should lead to fluctuations in nesting success in highly affected areas. Determining how coastal species respond to changes in the landscape is imperative for management of the habitat to mitigate the effects of severe storm activity.

METHODS

Study Sites

Two study sites were used for this project. The first was located along the east coast of southern Brevard County, Florida and extended north 40.5 km from Sebastian Inlet to the southern boundary of Patrick Air Force Base (Figure 1). The southern 21 km encompasses the Brevard County portion of the Archie Carr National Wildlife Refuge (ACNWR), while the northern 19.5 km is comprised of the Central Brevard Study Area (CBSA). The entire area is divided into ~0.5-km segments for sea turtle nest monitoring purposes. This stretch of beach hosts the highest density of loggerhead nesting in the western hemisphere (Ehrhart & Raymond 1983) as well as the highest density of green turtle nesting in the continental United States (Ehrhart & Raymond 1987). The entire site is open for public recreation and commercial and residential development occurs throughout, especially along the CBSA. Due to the extensive erosion sustained following the 2004 hurricane season, several types of restoration were utilized along the southern Brevard County study site. Approximately 78% of the ACNWR received emergency dune restoration using sand from an inland source. Within this area, only stretches of beach with structures on them (e.g. single family homes, condominiums, or hotels) were restored, creating a patchy distribution of adjacent restored and non-restored areas. Within the CBSA, a 6.5-km stretch at the southern end underwent full beach restoration (nourishment) to extend the width of the beach with sand dredged from offshore. Along the rest of the CBSA, emergency berms were constructed and supplemented with additional dune restoration; both required sand from an inland source (Figure 2).

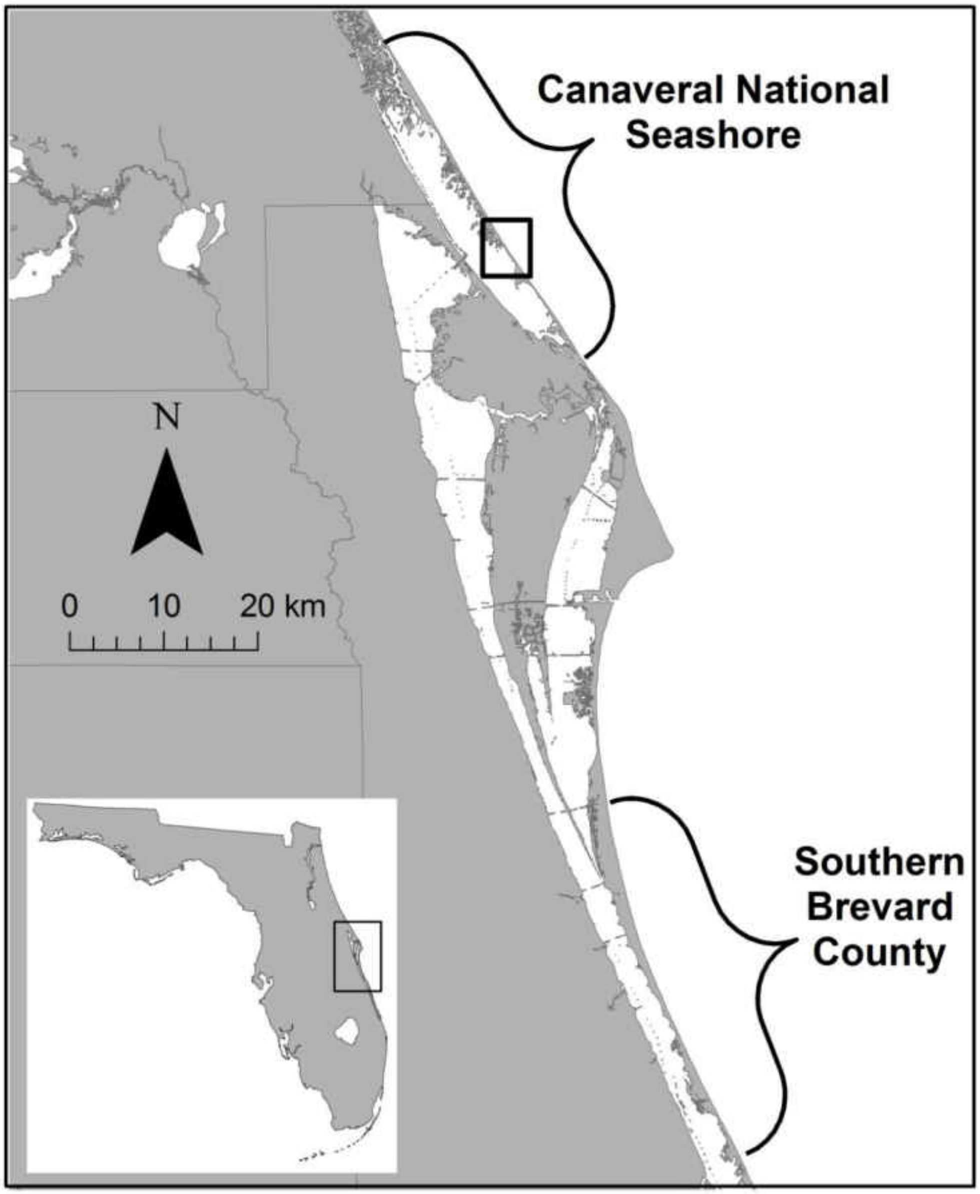


Figure 1. Map of the southern Brevard County and Canaveral National Seashore study sites. The boxed area of Canaveral National Seashore represents a 6-km area that was removed from all analyses due to a coverage gap in the LiDAR data.

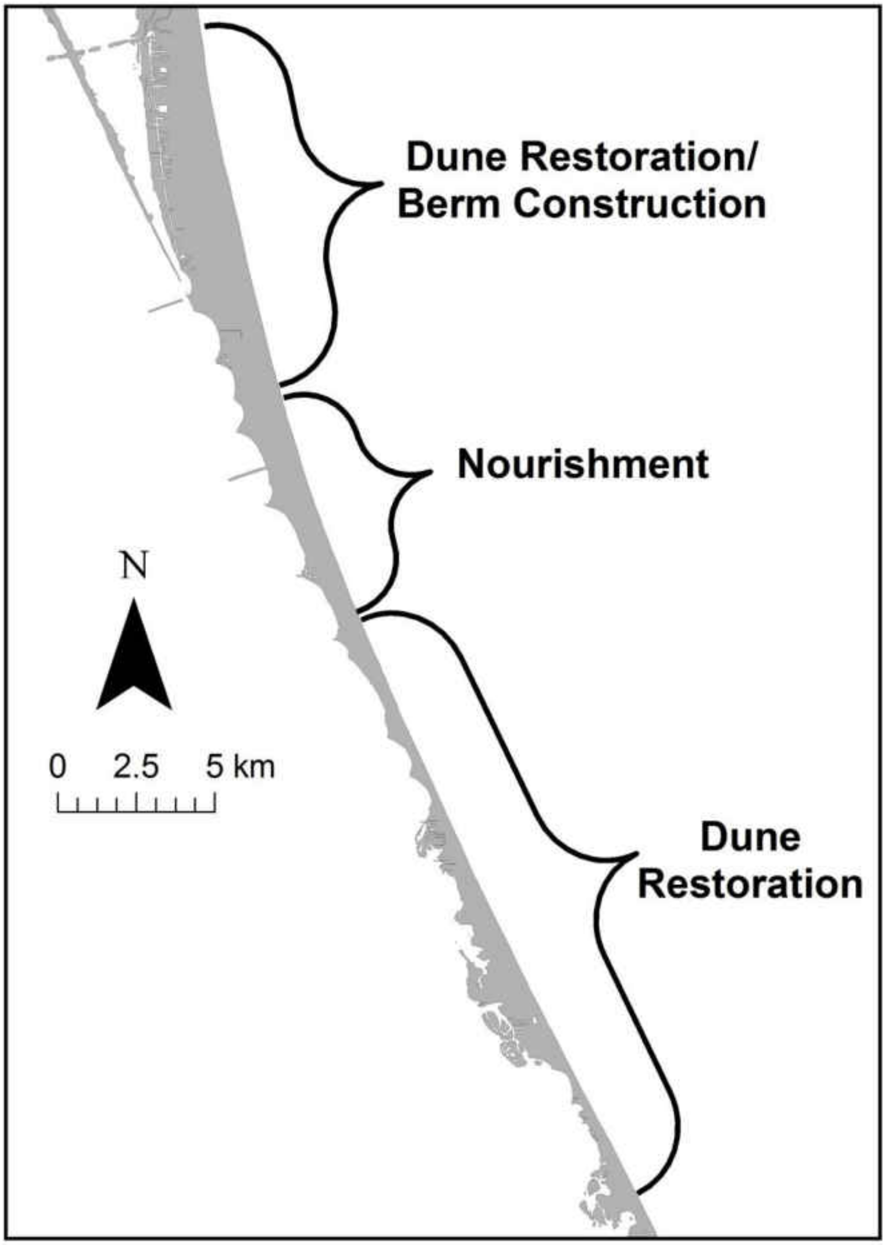


Figure 2. Map of the southern Brevard County study area with the placement of the various types of restoration used in 2005. Dune restoration covered approximately 78% of the southern portion with intermittent areas of non-restored beach.

The second study site extended from the southern portion of Volusia County, FL to northern Brevard County, FL and is comprised of Canaveral National Seashore (CNS, Figure 1). On average several thousand loggerhead nests and several hundred green turtle nests are laid on this beach each year (Antworth et al. 2006). Canaveral is an approximately 38.6-km stretch of undeveloped beach divided into ~0.4 km segments for monitoring. This site is also open for public recreation. Following the 2004 hurricane season no restoration took place, thus Canaveral is a relatively natural beach with adjacent development restricted to a few parking lots landward of the dunes with beach access points.

Nesting Data Collection

Nesting data were collected each summer between 1989 and 2005 by the University of Central Florida Marine Turtle Research Group for the Brevard County site and between 1995 and 2005 by CNS staff for the CNS site. Each morning from May through August the beach was surveyed and all sea turtle crawls were counted in each ~0.5-km (Brevard County) or ~0.4-km (CNS) segment. Crawls were identified to species and classified as either nesting or non-nesting emergences based on track characteristics. Collection of nesting data was standardized and followed the Index Nesting Beach Survey (INBS) protocols set forth by the Florida Fish and Wildlife Conservation Commission (Witherington & Koeppel 2000).

Remote Sensing Data Collection

LiDAR and IfSAR data were collected from a fixed-wing aircraft which was equipped with GPS and internal navigation. The two systems operate using swaths of pulsed light

(LiDAR) or radio waves (IfSAR). Several square kilometers can be easily covered in a single survey, allowing for evaluation of a much broader area than traditional ground survey methods. The sensor is flown parallel to the shoreline and emitted light or radio waves measure the distance to the ground. The return data are then used to calculate elevation, from which digital elevation models (DEM) and three-dimensional topographic maps may be created (Hodgson et al. 2003).

I obtained LiDAR elevation data for the Brevard County and CNS study sites between April and September 2008 from the National Oceanic and Atmospheric Administration Coastal Services Center (NOAA-CSC) website using the LiDAR Data Retrieval Tool. LiDAR data were collected using the Compact Hydrographic Airborne Rapid Total Survey system by the U.S. Army Corps of Engineers (USACE). According to the USACE, the data had a nominal ground spacing of 3 m and had a vertical accuracy of 15 cm root mean square error (RMSE) and a horizontal accuracy of 80 cm RMSE. I acquired data from missions flown in April 2004 (pre-hurricane), November 2004 (post-hurricane), and February 2006 (recovery period) which constitutes the period after restoration for the Brevard County site (Table 1). Due to coverage gaps in the post-hurricane dataset, I obtained IfSAR data from NOAA for CNS. All IfSAR data were collected by Intermap Technologies Inc. IfSAR data had a vertical accuracy of 1.0 m RMSE and a horizontal accuracy of 2.0 m RMSE. An additional coverage gap was found in the pre-hurricane LiDAR data for CNS; however no alternative remote sensing data were available for that time period. Because of this gap, a ~6-km segment of CNS was excluded from all analyses (Figure 1). I imported LiDAR (2-m resolution) and IfSAR (4.3-m resolution) data into ArcGIS 9.2 for spatial and topographic analyses. Additionally, I downloaded GPS locations for the restored areas of the Brevard County site into ArcGIS 9.2 and I classified each ~0.5-km segment by the extent of restoration it received in 2005: less than 50% restored (*n* = 7), or greater than 50% restored (*n* = 74). All 0.4-km segments of CNS were classified as 0% restored (*n* = 73). To assist with this classification I obtained aerial photos of the study areas (collected in November 2004) from the St. Johns River Water Management District (SJRWMD) GIS Library.

Topographic Characterization of Beach Segments

For consistency, I used public land use designations provided by the SJRWMD to include only remote sensing data in areas categorized as "beach" following the Florida Land Cover Classification System (Florida Department of Transportation 1999). I used Arc3D Analyst to calculate total sand volume above sea level and surface area in each ~0.5-km (Brevard) or ~0.4-km (CNS) segment for pre-hurricane, post-hurricane, and recovery period datasets. These variables have been used in previous studies of beach geomorphology to assess overall beach "health" (Cooper et al. 2000). For this study, they acted as indicators of the extent of erosion following the hurricanes and accretion during recovery. One of the most common and well-established methods of characterizing beach topography is to map profiles of the beach (Allen 1975; Caldwell & Williams 1985; Cooper et al. 2000), allowing for shoreline comparison. Using the Easy Profiler add-on tool for ArcMap (Huang 2005), I recorded profile measurements of the beach every 25 m along the entire length of both study areas for all three time periods. These profiles were perpendicular to the water line and extended inland to the top of the dune, recording elevation every 2 m. Using aerial photos of the study areas, the location of the top of the dune was determined for each segment individually to avoid including any beachside

Table 1. Remote sensing data for each time period at the Brevard County and Canaveral National Seashore sites.

Study Site	*Time Period*	*Date Collected*	*Type of Remote Sensing Used*	*Collected By*	*Horizontal Accuracy (RMSE)*	*Vertical Accuracy (RMSE)*
Brevard County	Pre-hurricane	April 2004	LiDAR	USACE	80 cm	15 cm
	Post-hurricane	November 2004	LiDAR	USACE	80 cm	15 cm
	Recovery period	February 2006	LiDAR	USACE	80 cm	15 cm
Canaveral National Seashore	Pre-hurricane	April 2004	LiDAR	USACE	80 cm	15 cm
	Post-hurricane	November 2004	IfSAR	Intermap Technologies Inc.	2 m	1 m
	Recovery period	February 2006	LiDAR	USACE	80 cm	15 cm

structures in the profile measurements. All profiles within each segment were then averaged. Following previous studies of coastal habitat, I used the average beach profiles to derive an overall linear slope (Goodale et al. 2007). I also divided the beach in half width-wise and calculated a linear slope for the upper and lower halves of the beach profiles and the ratio of the lower slope to the upper slope. Allen (1975) has suggested that linear slope measurements could potentially mask other features of the profile and the use of additional curve-fitting functions may be advantageous. I tested the profiles with several curves (e.g. exponential, polynomial, etc.) and found logarithmic and quadratic curves to fit the profiles well ($r^2 \approx 0.7$ and 0.9 respectively). To account for this curvilinear shape, I log-transformed the beach profiles and calculated the slope of the log-log model. Quadratic curves however, showed no relationship to nesting success and were not used in later analyses. Finally, I calculated an average width from the profiles as the distance from the water line to the top of the dune.

In addition to curve-fitting, fractal analysis is commonly used to characterize beach profiles (Southgate & Moller 2000; Gunawardena et al. 2008). Fractal dimension may be viewed as a measure of beach roughness as well as an indicator of spatial dependence (Palmer 1992). Because profiles may not be representative of an entire segment of beach, I calculated a fractal dimension for the entire surface of each ~0.5 or ~0.4-km segment. To derive fractal dimension, I created semivariograms to quantify topographic patterns of each beach segment at each time period. I then log-transformed both axes and calculated the linear slope (Burrough 1983; Palmer 1992). Following Usowicz and Lipiec (2009), I calculated the fractal dimension (D) as

$$D = 3 - m/2$$

where m is the slope of the log-transformed semivariogram.

Statistical Analyses

I used paired *t*-tests to determine if nesting success in each of the three restoration categories (0%, <50%, and >50% restored) differed from the 2004 nesting season to the 2005 nesting season, following the hurricanes and restoration projects. I also used paired *t*-tests to determine if each of the topographic variables differed between these time periods within the restoration categories. To correct for multiple comparisons I used a Bonferroni correction for each set of variable comparisons. To determine what combination of topographic variables significantly influenced nesting, I used multiple linear regression. I first built a correlation matrix to identify predictor variables that were collinear, and then built multiple regression models that excluded combinations of variables with a correlation coefficient greater than 0.5. I created two sets of multiple regression models: one set using the 2004 nesting and topography data and one using the 2005 data. Finally, I used Akaike's information criterion (AIC) to select the best regression model from each set.

Because of the possibility of patterns occurring at multiple spatial scales within this study, the impact of spatial autocorrelation needed to be considered. Spatial autocorrelation is a phenomenon in which ecological variables that are close together are more similar than expected at random (Legendre 1993). This tendency violates the statistical assumption of independence but is widely found in nature. To check for spatial autocorrelation I calculated Moran's I for each of the variables. Several methods have been offered to account for spatial autocorrelation at different stages in the experimental design process (Cliff & Ord 1981; Legendre 1993). To ensure that the spatial autocorrelation found in some of the variables did not influence the model, I again used Moran's I to check the residuals of each model (Dormann et al. 2007). As a cross-check to the previous method, I also extracted data at regular intervals beyond the scope of the spatial autocorrelation from each set of variables. I then carried out the regressions again using the subset of data and checked for similarity to the full models.

RESULTS

Loggerhead nesting success at the southern Brevard County site declined significantly from 2004 to 2005 in both restoration categories ($p < 0.01$ for <50% restored areas, $p < 0.001$ for >50% restored areas) (Figure 3), but green turtle nesting success showed a significant decline only in highly restored areas ($p < 0.001$) (Figure 3). Loggerhead and green turtle nesting success along this study site were moderately correlated in 2004 ($r^2 = 0.27$, $p < 0.0001$). In 2005, loggerhead and green turtle nesting success showed a low correlation, but only in highly restored areas ($r^2 = 0.15$, $p < 0.001$). At CNS loggerhead turtles showed a significant decline in nesting success ($p < 0.001$) while green turtle nesting success remained unchanged from 2004 to 2005 (Figure 3). Loggerhead and green turtle nesting success at CNS were slightly correlated, but only in 2005 ($r^2 = 0.14$, $p < 0.001$). In the 2005 nesting season, Brevard County had the lowest nesting success for loggerheads and green turtles since record-keeping began in 1989 and nesting success for both species was well below their long-term averages (Figure 4). Similarly, nesting success for both species at Canaveral National Seashore was below the long-term averages and loggerhead nesting success was the lowest on record since 1995 (Figure 5).

Changes in beach topography varied greatly among the three restoration categories. In the 0% restored areas (CNS), volume and width as well as the upper, lower, and log slopes changed significantly in response to the 2004 hurricanes ($p < 0.01$); however, volume and the log-log slope returned to their pre-hurricane levels by the 2005 nesting season and beach width almost recovered, though it was still narrower than in 2004. Surface area and fractal dimension declined significantly in that time (Figure 6). In less than 50% restored areas of Brevard County volume, surface area, width, and the log slope were all significantly affected by the hurricanes

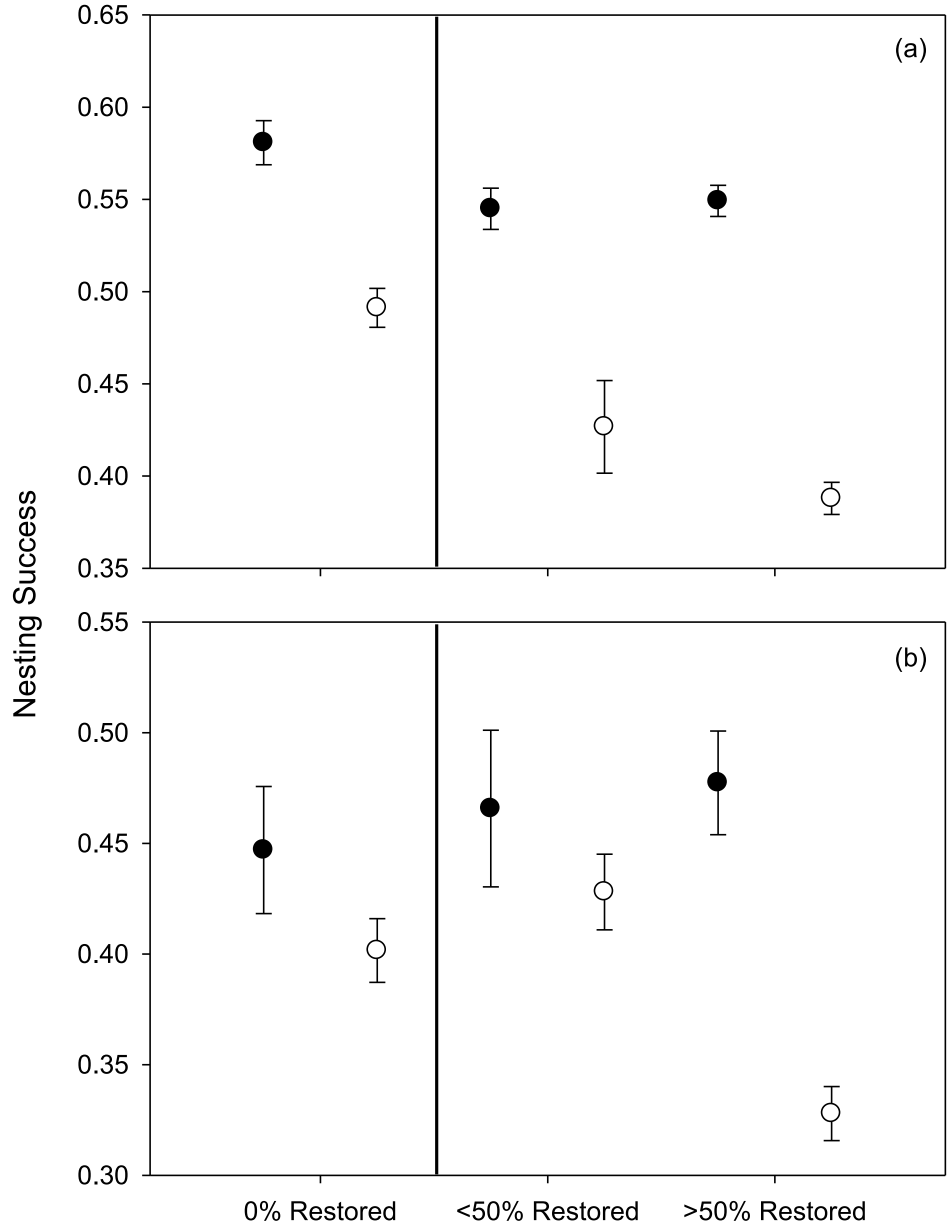


Figure 3. Nesting success for loggerheads (a) and green turtles (b) in 2004 (black) and 2005 (white) in each of the three restoration categories. Bars indicate the standard error.

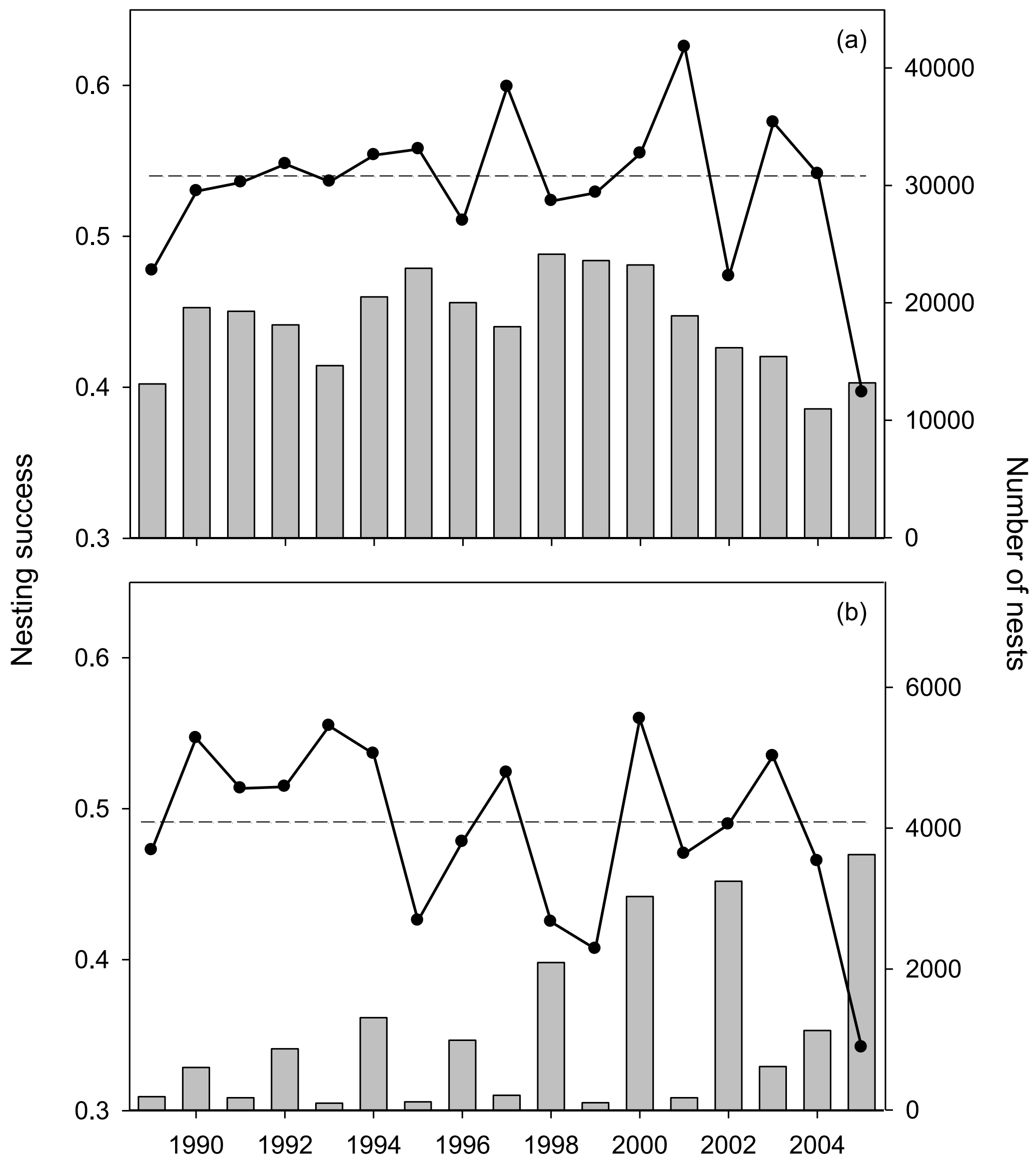


Figure 4. Yearly nesting success (solid black lines) at the southern Brevard County site for loggerheads (a) and green turtles (b) recorded since 1989. The dashed lines represent the long-term average nesting success for each species and the bars represent the total number of nests each year.

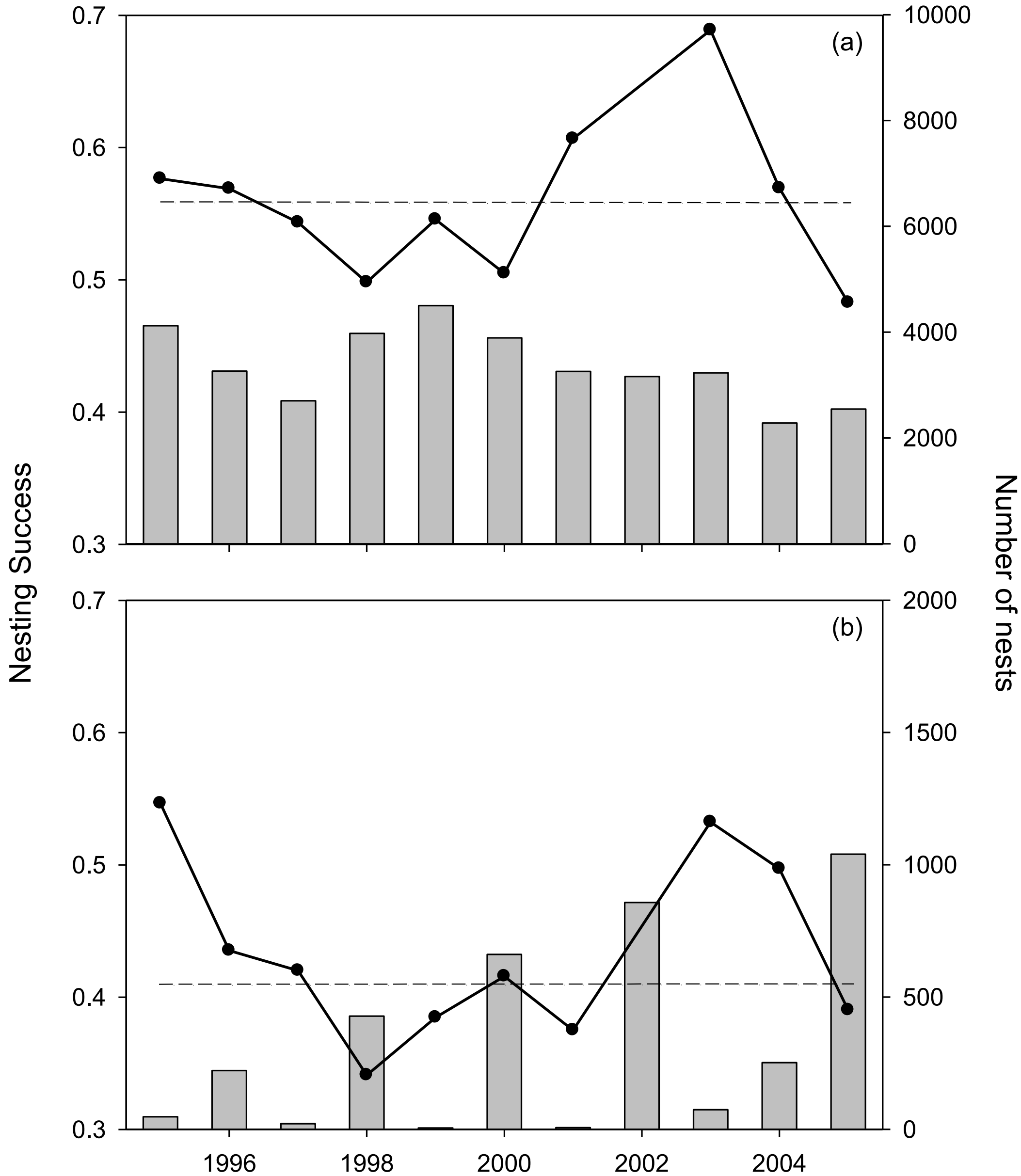


Figure 5. Yearly nesting success (solid black lines) at Canaveral National Seashore for loggerheads (a) and green turtles (b) recorded since 1995. The dashed lines represent the long-term average nesting success for each species and the bars represent the total number of nests each year.

($p < 0.01$) and none of these variables recovered by the 2005 nesting season (Figures 6 and 7). Similarly, greater than 50% restored areas of Brevard County experienced significant changes in volume, surface area, width, and log slope ($p < 0.001$) (Figures 6 and 7). Further significant changes in volume, width, overall slope, lower slope, and fractal dimension ($p < 0.001$) following the various beach restoration projects caused several variables to be significantly different in the 2005 nesting season than in the 2004 nesting season ($p < 0.001$) (Figures 6-8). Within both study areas some topographic variables showed significant spatial autocorrelation (especially the slope and log slope), while the rest did not.

Between the two study areas, loggerheads appeared to show a more consistent response to topographic variables than green turtles. For the Brevard County site, loggerhead nesting success in 2004 was best predicted by a model that included the log slope, upper slope, and slope ratio and in 2005, after the hurricanes and restoration, by the width and upper slope (Table 2). Within these models, the width, log slope and upper slopes were significant. Nesting success for green turtles in this area was best predicted by the width and slope ratio in 2004 and by volume and the overall slope in 2005 (Table 2). At the CNS site, overall slope and lower slope seemed to be most influential for loggerheads in 2004, while width, log slope, and lower slope influenced nesting success in 2005 after the hurricanes (Table 2). Green turtles in this area displayed much less consistency, responding to surface area in 2004 and to upper slope in 2005 (Table 2). High spatial autocorrelation was not found in the residuals of any of the best-fit models and the cross-check method using subsets of the data yielded similar results to those of the full models.

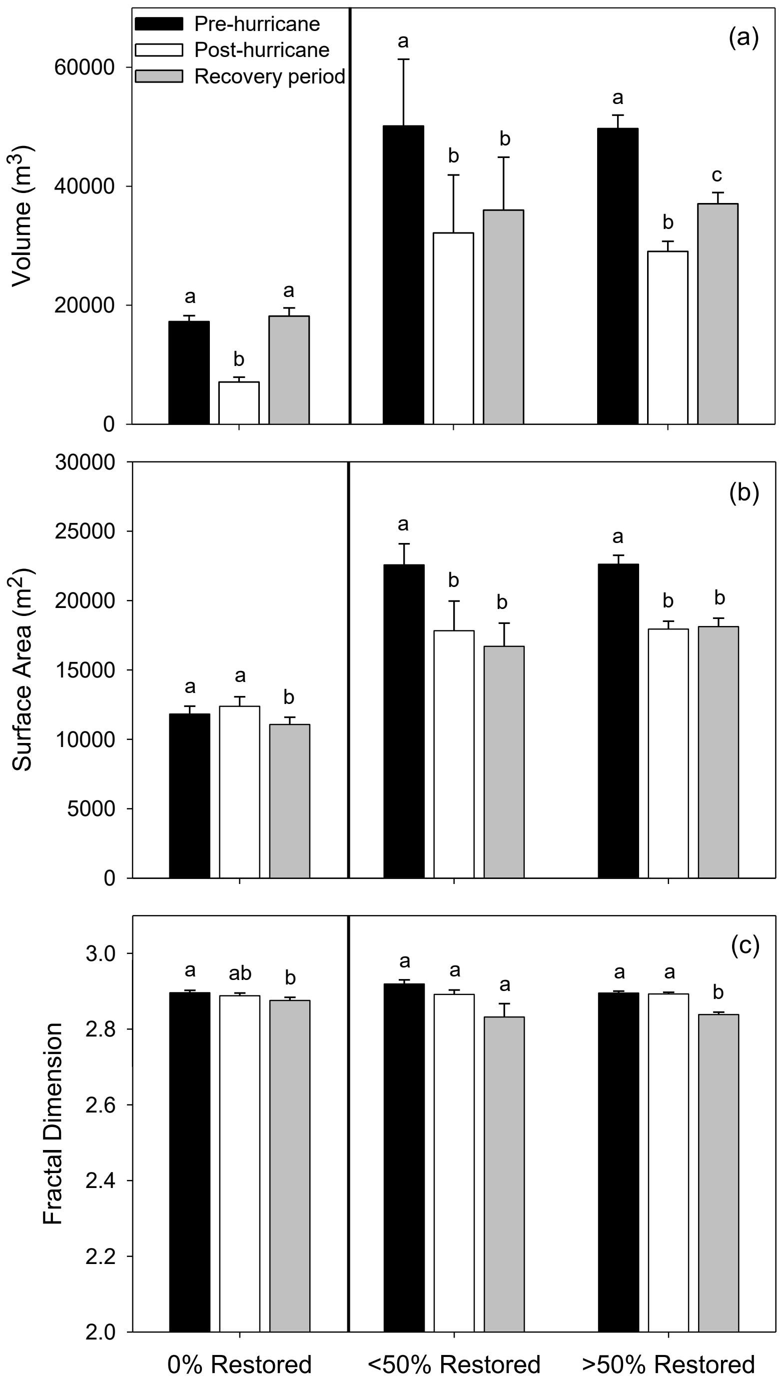


Figure 6. Volume (a), surface area (b), and fractal dimension (c) calculated for each restoration category at each time period. Differing letters indicate measurements that are significantly different from each other within a restoration category and bars indicate the standard error.

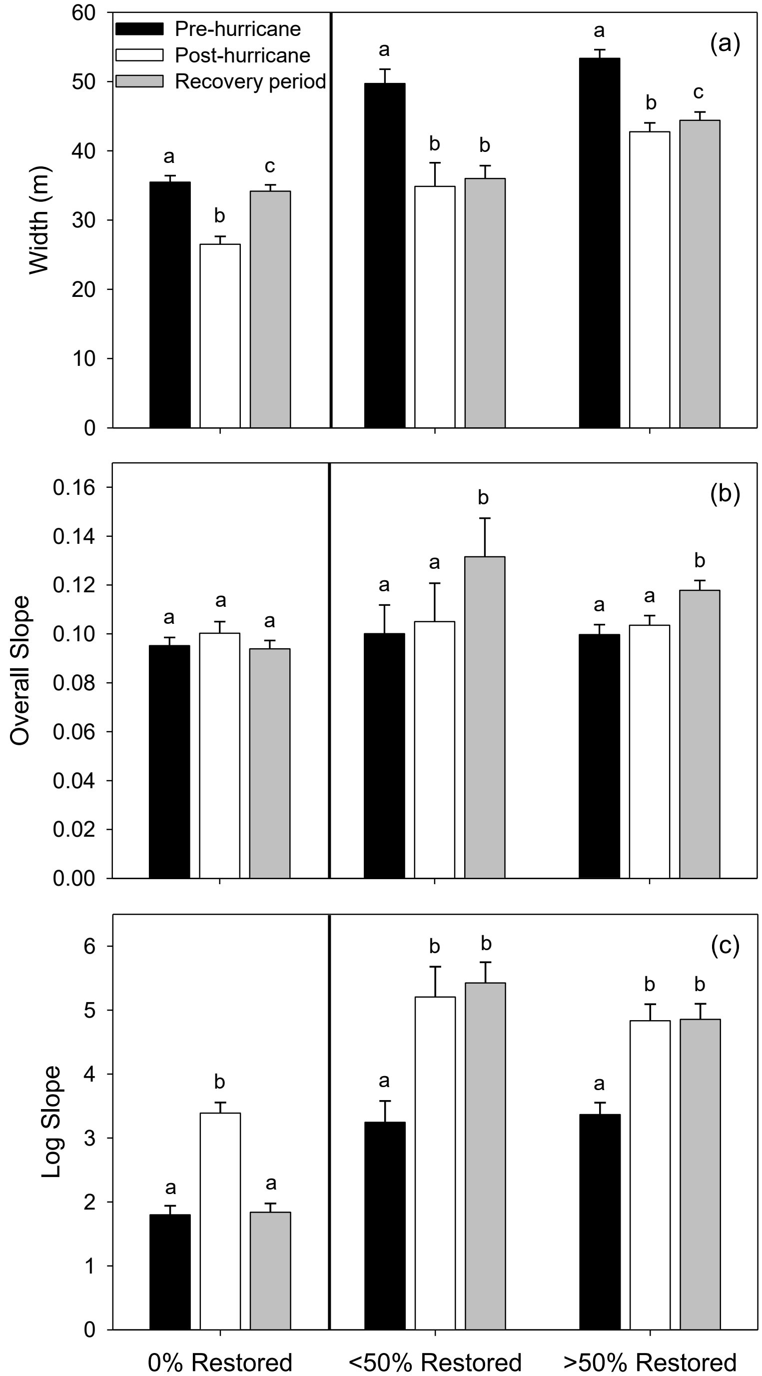


Figure 7. Average width (a), overall slope (b), and log slope (c) calculated for each restoration category at each time period. Differing letters indicate measurements that are significantly different from each other within a restoration category and bars indicate the standard error.

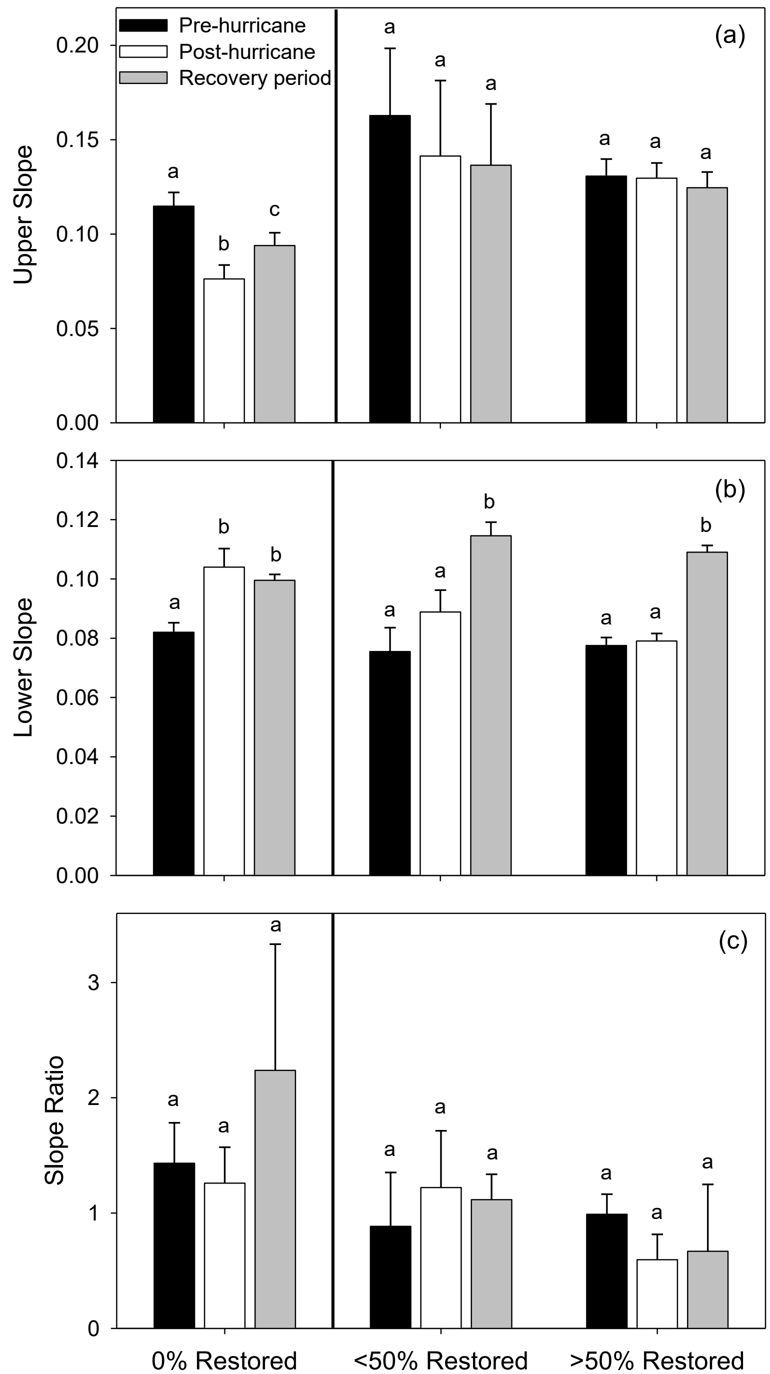


Figure 8. Average upper slope (a), lower slope (b), and slope ratio (c) calculated for each restoration category at each time period. Differing letters indicate measurements that are significantly different from each other within a restoration category and bars indicate the standard error.

Table 2. Top three best-fit multiple regression models for loggerhead and green turtles at the Brevard County and Canaveral National Seashore sites ranked by AIC and Akaike weights (w_i). *Indicates variables that are significant within the model.

Brevard County 2004					
Loggerheads			*Green Turtles*		
Model Variables	*AIC*	w_i	*Model Variables*	*AIC*	w_i
-Upper Slope* + Log Slope* - Ratio*	-213.43	0.62	-Width* - Ratio*	-46.29	0.29
-Upper Slope* + Overall Slope - Ratio*	-212.16	0.33	-Width* - Lower Slope*	-46.23	0.28
-Upper Slope* + Overall Slope* - Width*	-207.08	0.03	-Width* - Lower Slope* + Log Slope	-44.24	0.10

Brevard County 2005					
Loggerheads			*Green Turtles*		
Model Variables	*AIC*	w_i	*Model Variables*	*AIC*	w_i
Width* + Upper Slope*	-202.14	0.45	Overall Slope* + Volume	-132.69	0.16
Width* + Upper Slope* - Log Slope	-200.51	0.20	Overall Slope	-131.37	0.08
Width* + Upper Slope* - Overall Slope	-200.16	0.17	Overall Slope* + Volume - Fractal Dimension	-130.98	0.07

Canaveral National Seashore 2004					
Loggerheads			*Green Turtles*		
Model Variables	*AIC*	w_i	*Model Variables*	*AIC*	w_i
Overall Slope* - Lower Slope	-118.87	0.18	-Surface Area*	32.83	0.19
Overall Slope* + Upper Slope	-117.75	0.10	-Volume	33.95	0.11
Overall Slope*	-117.59	0.09	-Surface Area* - Overall Slope	34.69	0.07

Canaveral National Seashore 2005					
Loggerheads			*Green Turtles*		
Model Variables	*AIC*	w_i	*Model Variables*	*AIC*	w_i
Width* - Log Slope* + Lower Slope*	-143.19	0.34	Upper Slope*	-75.57	0.15
Width* - Log Slope* + Upper Slope*	-142.27	0.21	Upper Slope* + Width	-75.46	0.14
Width* + Overall Slope*	-140.63	0.10	Upper Slope* - Overall Slope	-74.53	0.09

DISCUSSION

The results demonstrate that hurricanes and beach restoration both have profound effects on the topography of the beach. Volume, surface area, and width were all greatly reduced following hurricane activity in 2004, indicating high levels of erosion and a smoothing of the beach surface. Sallenger et al. (2006) noted that in some areas of the east coast, erosion caused retreat of the dunes by as much as 11 m. This was likely exacerbated by the fact that Hurricanes Frances and Jeanne made landfall within three weeks of each other in almost the same location (National Hurricane Center 2005). The storms also impacted the shape of the beach's profile, increasing the steepness of the logarithmic curvature of the profiles and at CNS, impacting both the upper and lower slopes. The formation of scarps due to erosion is likely the cause of this change, as scarps are a common result of intense storm activity (Morton & Sallenger 2003) and can be found in the post-hurricane remote sensing data. Scarp formation may explain why the logarithmic curvature of the profiles was affected but overall slopes were not (Figure 9).

At CNS most hurricane-induced changes in beach morphology were either completely reversed or in the process of recovering by the 2005 nesting season with the exception of the lower slope. Morton et al. (1994) identified four stages of natural beach recovery following severe storm erosion with berm and forebeach recovery being the first stage. This stage is noted to last from several months to approximately a year, which is consistent with the findings of the current study. Southern Brevard County however, did not experience the same recovery in beach morphology. Because of their positions along Florida's coastline, CNS and the Brevard County site may experience different patterns of accretion leading to different rates of beach recovery.

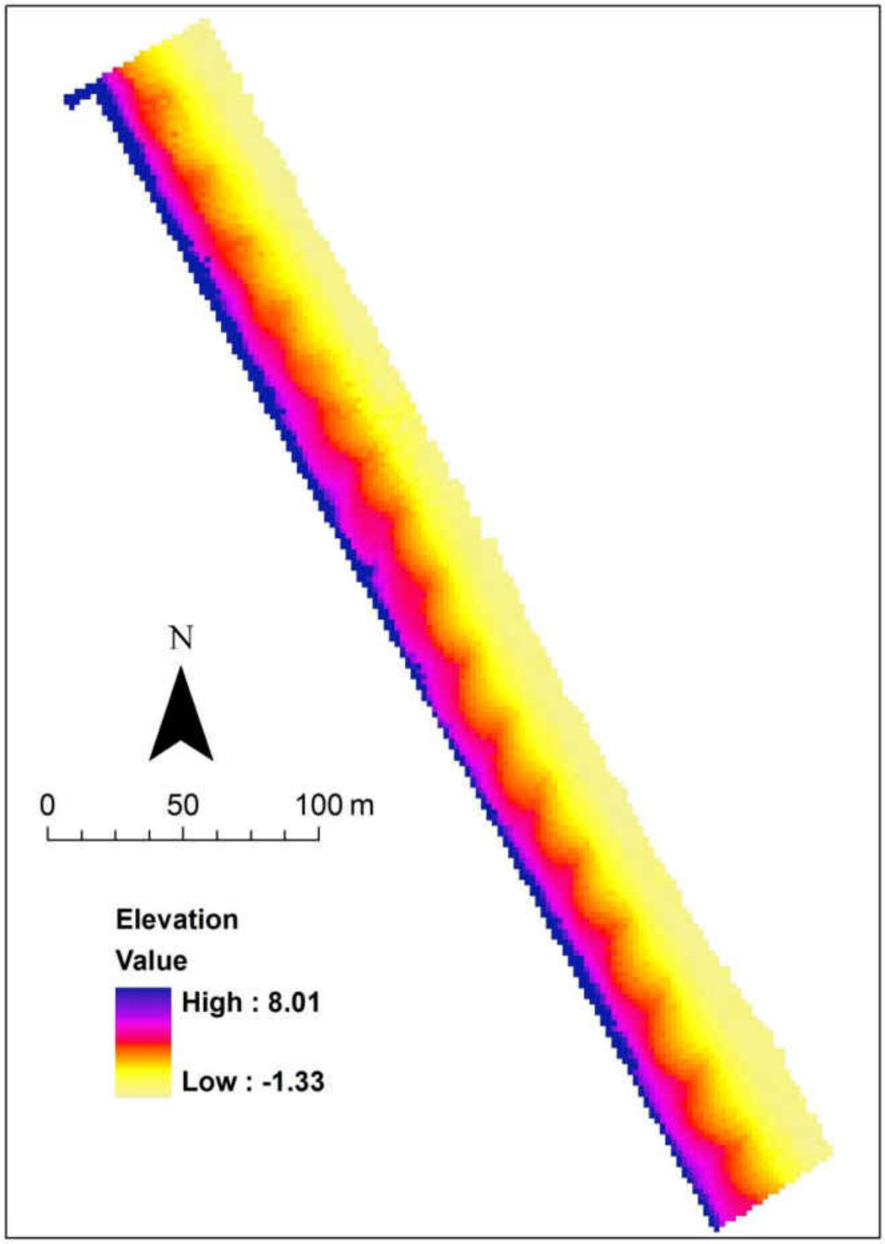


Figure 9. LiDAR imagery of a 0.5-km segment of the southern Brevard County study area following the 2004 hurricanes. The sudden shift in color from orange to red to magenta indicates a rapid change in elevation consistent with scarp formation.

Beach and dune restoration in southern Brevard County also had an impact on beach morphology. Sand placed on the beach in highly restored areas (>50% restoration) increased the total volume and beach width, but not enough to return to pre-hurricane measurements. This may be because only a small stretch of the shoreline received full beach restoration (nourishment) while the rest of the restored areas focused mainly on the dunes. Engineering of the dunes may also explain the increase in overall slope following the restoration as well as the decrease in fractal dimension. Restored dunes are likely to have a slightly smoother surface than natural dunes and should exhibit more spatial dependence because of the uniform nature defined by their engineering requirements, which often specify a particular shape or slope to be used throughout the project (Campbell et al. 2005). Together, the hurricane-induced and restoration-induced changes in topography in highly restored areas created beach morphology for the 2005 nesting season that was completely different from that of the 2004 season.

Because two different types of remote sensing data were needed to cover Canaveral National Seashore, differences between the LiDAR and IfSAR need to be considered. Although the relationship between LiDAR and IfSAR was not strong, LiDAR tended to return higher elevation data (see Appendix D for further explanation). While this could cause significant error in the volume measurements, the other topographic variables should be less affected. Surface area and fractal dimension measurements were taken at the surface, thus elevation would not be an influence. An underestimation of elevation should minimally affect the profile measurements as the shape of the profiles would remain intact despite an overall loss of elevation. Furthermore, IfSAR data were not used in relation to any nesting data and therefore did not impact the relationships seen between nesting success and topography.

As demonstrated by the results, changes in beach topography have differing impacts on loggerhead and green turtles. It is well documented that restoration projects have a negative effect on sea turtle nesting (Crain et al. 1995; Steinitz et al. 1998; Rumbold et al. 2001; Brock et al. 2009). Brock et al. (2009) found equal negative impacts of restored beaches on loggerhead and green turtles, but the majority of previous studies have focused on loggerheads. In the present study loggerhead nesting success declined in all three restoration categories, though green turtle nesting success declined only in highly restored areas. Similar to the findings of Brock et al. (2009), this pattern suggests that loggerheads may be more sensitive to overall topographic changes while green turtles respond to more specific changes associated with restoration. Witherington et al. (2009) have reported a decrease in statewide nest counts of loggerhead nests, though nesting success has not declined. Therefore, the decrease in nesting success seen here is probably not a product of the statewide decline in nesting.

Loggerheads appeared to respond to morphologic variables more consistently than green turtles in both study areas, specifically to aspects of profile shape. Upper slope was a common predictor for loggerheads in Brevard County and was a significant variable in 2004 and 2005. Loggerheads around the state of Florida tend to nest preferentially between the vegetation border of the supra-littoral zone (Hays et al. 1995) and approximately 2 m seaward of the dune face (Wood & Bjorndal 2000). Wood and Bjorndal (2000) found that females on this beach tended to nest most often where the slope at the position of the nose was steeper than at the position of the cloaca. The correlation between nesting success and the slope of the upper portion of the beach seen here confirms that female loggerheads recognize the increase in slope from foredune to dune as a cue to nest (Wood & Bjorndal 2000). At CNS the lower slope rather than upper slope was the common predictor from 2004 to 2005, perhaps demonstrating plasticity in the mechanism of nest site selection depending on location. This area is typically narrower than the beaches in the Brevard County study area leading to an increased probability of tidal inundation of the nests. An increased lower slope may point to higher areas of drier nest sites. Beach width was significantly correlated with nesting success for loggerheads in both study areas but only in 2005. Loggerheads have been shown to prefer moderately wide beaches (e.g. approximately 30 – 50 m on the east coast of Florida) when selecting a nest site (Provancha & Ehrhart 1987; Garmestani et al. 2000; Mazaris et al. 2006), thus significantly narrower beaches in 2005 may have left nesting females looking for wider sections of beach to nest on.

Green turtles appeared to be less influenced by morphologic characters than loggerheads. Though aspects of the profile had some effect, they were highly inconsistent and other variables such as volume and surface area were included in some of the best-fit models. Green turtles tend to crawl further and nest higher in the dunes than loggerheads (Hays et al. 1995) and previous work in Brevard County revealed that emerging green turtles that reached the dune on a restored beach were more likely to nest than those that did not (Brock et al. 2009). This behavior was initially attributed to dune morphology but the present study failed to find any consistent relationships with topography. Green turtles, however, have also been shown to prefer moderately vegetated areas when selecting a nest site (Chen et al. 2007), thus females may be more influenced to nest by dune features such as the presence or abundance of vegetation than by morphology.

Spatial autocorrelation is a common phenomenon in natural systems, though it violates the statistical assumption of independence. In the present study, some variables exhibited significant spatial autocorrelation (e.g. nesting success, slope and log slope) while others did not (e.g. surface area and fractal dimension). To account for this, I used a two-part cross-check system to estimate the influence of known spatial autocorrelation on the observed nesting patterns. High spatial autocorrelation was not found in the regression model residuals, indicating that the patterns were not simply a product of autocorrelation. Furthermore, regressions using extracted data beyond the scale of autocorrelation found in the variables produced results consistent with the full models. This cross-check system allows for increased confidence that spatial autocorrelation was not responsible for the significant regressions, but rather that a true pattern exists.

Severe storm activity has been on the rise, increasing public demand for beachside structures to be protected from high levels of erosion. Beach restoration has become the preferred method of managing erosion along much of the Florida coast; however this process leaves the landscape highly altered. Research has shown that beach restoration projects may have negative consequences for some already fragile inhabitants including piping plovers (Melvin et al. 1991) and horseshoe crabs (Avissar 2006) as well as sea turtles (Crain et al. 1995; Rumbold et al. 2001; Brock et al. 2009; Long et al. in press). By understanding how topography affects the species that utilize coastal habitat, beach restoration projects can be tailored to restore the beach to a more natural morphology and minimize their negative impact. Previous studies have indicated that mirroring non-restored adjacent beaches or avoiding large contiguous areas of restoration can help reduce the ecological impact (Steinitz et al. 1998; Brock et al. 2009).

The use of remote sensing allows management agencies to assess along-shore morphology at multiple spatial scales. This ability will highlight specific areas of severe erosion and reduce the need to restore large stretches of beach with a single profile template, thereby reducing the ecological as well as economic impact. The use of remote sensing systems such as LiDAR and IfSAR to map coastal ecosystems offers an efficient way to evaluate sea turtle nesting habitat. By conducting broad surveys of the shoreline with a high degree of accuracy, even minor changes in morphology can be assessed. The ability to quickly and accurately assess changes in beach morphology through remote sensing analyses will allow for the development of site-specific restoration projects, expediting the management process while maintaining dune morphologies that promote increased habitat functionality.

CONCLUSIONS

Based on the results of this study, landscape level changes in beach topography can have a dramatic effect on sea turtle nesting success, particularly in the case of beach restoration. For areas undergoing restoration it may behoove coastal engineers to attempt to reproduce the profile shapes of adjacent non-restored beaches. Specifically, the use of defined dune and foredune slopes should allow for higher loggerhead nesting success than an overall gradual slope across the width of the beach. To maintain high loggerhead nesting success, restoration projects should aim to create beaches of moderate width; for this study beaches approximately 30 – 50 m wide seemed to support the highest nesting success. On narrower beaches, slightly increased slopes on the lower half of the beach may help improve nesting success. For green turtles, further work is needed to better examine the relationship between nesting and the presence and abundance of dune vegetation. Areas of severe dune erosion and subsequent restoration will likely have little to no vegetation present following the restoration, thus vegetation planting may be required to maintain high green turtle nesting success.

Beach restoration techniques have the potential to be beneficial to nesting sea turtles provided that landscape preferences such as width and profile shape are taken into consideration. It is important to note that the use of a general template for restoration should be discouraged due to the high variation in coastal morphology. For specific regions, assessing the topography in relation to nesting patterns should provide insight into the most favorable widths and slopes for a particular nesting beach. By mimicking the natural morphology of preferred nesting beaches and reducing the scale of the project, beach restoration can potentially maintain high sea turtle nesting success while still protecting beachside property.

APPENDIX A: 2004 AND 2005 NESTING SUCCESS

Note: Segments 49 – 64 (north to south) of Canaveral National Seashore were removed from all analyses due to a coverage gap in the pre-hurricane LiDAR data.

Southern Brevard County

Segment	Loggerhead 2004	Loggerhead 2005	Green Turtle 2004	Green Turtle 2005
1	0.739	0.261	0.625	0.091
2	0.681	0.379	0.571	0.455
3	0.644	0.403	0.667	0.500
4	0.667	0.374	0.875	0.333
5	0.638	0.382	0.333	0.353
6	0.575	0.282	0.000	0.316
7	0.697	0.247	0.667	0.313
8	0.629	0.243	0.125	0.444
9	0.635	0.368	0.625	0.455
10	0.608	0.361	0.846	0.346
11	0.635	0.353	0.857	0.222
12	0.649	0.374	0.600	0.458
13	0.620	0.399	0.600	0.600
14	0.600	0.429	0.800	0.444
15	0.680	0.277	0.833	0.357
16	0.621	0.355	0.750	0.250
17	0.590	0.291	0.500	0.429
18	0.635	0.248	1.000	0.200
19	0.671	0.350	0.733	0.364
20	0.450	0.349	0.545	0.600
21	0.611	0.339	0.846	0.323
22	0.668	0.349	0.857	0.275
23	0.477	0.364	0.500	0.333
24	0.480	0.366	0.300	0.232
25	0.508	0.407	0.000	0.351
26	0.525	0.436	0.167	0.265
27	0.533	0.302	0.182	0.000
28	0.417	0.329	0.400	0.143
29	0.448	0.353	0.417	0.280
30	0.523	0.438	0.375	0.222
31	0.531	0.427	0.111	0.359
32	0.530	0.455	0.533	0.433
33	0.570	0.432	0.385	0.267
34	0.458	0.426	0.267	0.108
35	0.479	0.435	0.238	0.279
36	0.514	0.437	0.267	0.410
37	0.547	0.444	0.207	0.366
38	0.478	0.506	0.345	0.397
39	0.421	0.359	0.407	0.375
40	0.527	0.316	0.478	0.437
41	0.610	0.335	0.545	0.237
42	0.569	0.270	0.341	0.173

	Loggerhead		Green Turtle	
Segment	2004	2005	2004	2005
43	0.520	0.355	0.515	0.359
44	0.519	0.379	0.596	0.377
45	0.582	0.428	0.590	0.372
46	0.543	0.397	0.587	0.404
47	0.568	0.450	0.413	0.302
48	0.552	0.410	0.488	0.387
49	0.543	0.537	0.375	0.514
50	0.543	0.486	0.547	0.417
51	0.584	0.460	0.508	0.478
52	0.551	0.424	0.483	0.258
53	0.535	0.380	0.529	0.236
54	0.573	0.324	0.410	0.298
55	0.500	0.302	0.492	0.326
56	0.571	0.307	0.512	0.242
57	0.544	0.349	0.535	0.204
58	0.507	0.416	0.343	0.324
59	0.511	0.435	0.579	0.263
60	0.521	0.443	0.174	0.359
61	0.563	0.505	0.486	0.455
62	0.476	0.534	0.400	0.336
63	0.496	0.360	0.483	0.233
64	0.473	0.253	0.417	0.152
65	0.427	0.347	0.404	0.254
66	0.518	0.371	0.400	0.374
67	0.502	0.459	0.375	0.349
68	0.520	0.444	0.531	0.317
69	0.507	0.428	0.326	0.295
70	0.518	0.344	0.500	0.339
71	0.467	0.305	0.364	0.217
72	0.530	0.480	0.500	0.408
73	0.415	0.432	0.473	0.351
74	0.594	0.453	0.436	0.387
75	0.462	0.502	0.554	0.383
76	0.481	0.445	0.431	0.391
77	0.602	0.535	0.617	0.428
78	0.517	0.533	0.377	0.452
79	0.551	0.480	0.439	0.424
80	0.500	0.594	0.400	0.408
81	0.484	0.349	0.273	0.390

Canaveral National Seashore

Segment	Loggerhead 2004	Loggerhead 2005	Green Turtle 2004	Green Turtle 2005
1	0.688	0.600	0.000	0.714
2	0.533	0.600	0.500	0.308
3	0.792	0.577	0.000	0.444
4	0.467	0.406	0.333	0.667
5	0.500	0.594	0.000	0.364
6	0.750	0.600	1.000	0.500
7	0.533	0.583	0.000	0.615
8	0.458	0.561	1.000	0.875
9	0.692	0.710	0.333	0.400
10	0.583	0.590	0.500	0.538
11	0.733	0.636	0.000	0.400
12	0.545	0.636	0.000	0.222
13	0.750	0.560	1.000	0.556
14	0.857	0.558	0.667	0.438
15	0.682	0.421	0.500	0.360
16	0.586	0.405	0.500	0.286
17	0.520	0.320	0.000	0.611
18	0.810	0.391	0.333	0.471
19	0.609	0.358	1.000	0.382
20	0.720	0.486	0.000	0.357
21	0.768	0.536	0.000	0.463
22	0.750	0.478	0.250	0.538
23	0.611	0.583	0.500	0.429
24	0.700	0.586	0.667	0.464
25	0.684	0.526	0.000	0.636
26	0.600	0.617	0.750	0.500
27	0.657	0.538	0.500	0.217
28	0.641	0.649	0.000	0.385
29	0.630	0.447	0.600	0.258
30	0.656	0.604	0.571	0.467
31	0.656	0.528	0.500	0.389
32	0.594	0.576	0.286	0.227
33	0.621	0.641	0.667	0.556
34	0.688	0.569	0.286	0.170
35	0.774	0.565	0.444	0.405
36	0.818	0.429	0.857	0.343
37	0.659	0.610	0.250	0.263
38	0.548	0.600	1.000	0.333
39	0.511	0.433	0.500	0.333
40	0.653	0.526	0.600	0.158
41	0.592	0.500	0.667	0.478
42	0.569	0.595	0.500	0.471

	Loggerhead		Green Turtle	
Segment	2004	2005	2004	2005
43	0.521	0.326	0.600	0.333
44	0.391	0.390	0.250	0.389
45	0.500	0.308	0.286	0.405
46	0.711	0.450	0.900	0.353
47	0.518	0.463	0.500	0.298
48	0.534	0.468	0.286	0.353
65	0.467	0.472	0.571	0.333
66	0.500	0.323	0.714	0.111
67	0.582	0.510	0.667	0.647
68	0.606	0.556	0.714	0.346
69	0.361	0.319	0.500	0.219
70	0.367	0.528	1.000	0.375
71	0.311	0.341	0.167	0.375
72	0.333	0.393	0.600	0.241
73	0.345	0.421	0.250	0.235
74	0.302	0.443	0.143	0.246
75	0.379	0.368	0.333	0.205
76	0.632	0.228	1.000	0.237
77	0.563	0.392	0.500	0.484
78	0.643	0.476	0.000	0.286
79	0.419	0.388	0.500	0.324
80	0.360	0.373	0.500	0.242
81	0.423	0.307	0.000	0.120
82	0.583	0.374	0.000	0.262
83	0.636	0.500	0.200	0.452
84	0.567	0.628	0.500	0.632
85	0.486	0.509	0.200	0.622
86	0.565	0.552	0.500	0.611
87	0.615	0.389	0.000	0.391
88	0.596	0.438	0.500	0.293
89	0.571	0.495	0.333	0.365
90	0.547	0.547	0.467	0.486
91	0.616	0.505	0.300	0.575
92	0.475	0.607	0.625	0.462
93	0.576	0.556	0.500	0.600

APPENDIX B: TOPOGRAPHIC VARIABLES

Note: Segments 49 – 64 (north to south) of Canaveral National Seashore were removed from all analyses due to a coverage gap in the pre-hurricane LiDAR data.

Southern Brevard County

Pre-Hurricane

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
1	33699.85	18914.70	2.937	48	0.097	2.998	0.063	0.063	1.004
2	73374.07	26991.20	2.913	58	0.106	2.410	0.072	0.097	0.739
3	56407.32	23985.53	2.915	50	0.100	3.047	0.047	0.090	0.521
4	54307.20	23206.21	2.896	52	0.109	3.591	0.038	0.113	0.337
5	65378.61	24368.30	2.944	48	0.108	3.308	0.092	0.102	0.904
6	31822.86	17691.92	2.936	50	0.112	3.413	0.127	0.024	5.329
7	28085.34	16373.33	2.903	60	0.092	2.256	0.135	-0.032	-4.261
8	23212.52	16685.28	2.849	60	0.085	1.824	0.097	0.045	2.135
9	25369.24	18282.99	2.929	42	0.088	3.267	0.075	0.104	0.725
10	21285.35	14839.70	2.891	38	0.076	3.908	0.088	0.049	1.793
11	30172.18	18995.45	2.936	36	0.076	4.465	0.078	0.108	0.720
12	86527.57	27164.73	2.890	44	0.073	3.913	0.061	0.068	0.898
13	42367.51	22145.80	2.912	40	0.084	4.075	0.076	0.117	0.649
14	54568.45	24192.45	2.831	40	0.110	3.717	0.079	0.187	0.420
15	19770.01	16140.63	2.929	54	0.092	2.225	0.051	0.130	0.388
16	22836.05	18544.53	2.948	48	0.118	3.269	0.076	0.166	0.456
17	40604.15	21690.01	2.904	38	0.064	3.713	0.071	0.050	1.414
18	35042.25	21667.02	2.948	44	0.053	3.040	0.057	0.073	0.784
19	31584.07	18446.00	2.887	50	0.102	3.976	0.059	0.195	0.302
20	26328.14	18377.15	2.902	44	0.079	4.855	0.071	0.131	0.539
21	43030.73	27290.83	2.905	42	0.114	6.029	0.086	0.183	0.468
22	40752.03	24329.29	2.917	54	0.061	3.790	0.025	0.095	0.265
23	46822.61	19817.92	2.864	54	0.064	2.282	0.034	0.157	0.217
24	61399.85	29430.05	2.921	54	0.052	2.467	0.051	0.079	0.647
25	90824.20	34785.86	2.927	62	0.068	3.218	0.070	0.087	0.803
26	62976.76	29770.29	2.864	68	0.141	1.980	0.083	0.128	0.648
27	61472.57	28939.95	2.836	60	0.056	1.776	0.081	0.031	2.572
28	64441.53	32896.56	2.856	60	0.048	1.666	0.090	0.011	8.314
29	57396.58	29378.30	2.841	68	0.036	1.073	0.069	0.011	6.279
30	60206.77	29366.28	2.895	70	0.034	0.915	0.073	0.019	3.828
31	58615.35	29349.09	2.887	68	0.039	0.448	0.071	0.030	2.399
32	57676.21	29301.02	2.883	66	0.044	1.187	0.084	0.036	2.311
33	46809.73	24835.91	2.874	60	0.042	1.497	0.094	0.014	6.621
34	38831.53	19761.25	2.894	66	0.038	0.912	0.060	0.015	3.907
35	77004.45	38397.28	2.928	68	0.041	1.294	0.067	0.020	3.443
36	68271.57	29606.39	2.910	74	0.075	0.825	0.065	0.106	0.610
37	73099.05	28188.54	2.921	68	0.087	0.439	0.065	0.162	0.402
38	52490.18	25609.03	2.905	58	0.097	0.834	0.071	0.162	0.436
39	45918.06	23280.62	2.921	58	0.059	0.329	0.041	0.081	0.511
40	43850.35	22620.79	2.916	54	0.084	2.097	0.080	0.123	0.650

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
41	29776.46	15176.26	2.934	56	0.086	2.971	0.069	0.127	0.546
42	33046.40	18076.09	2.931	42	0.119	6.327	0.089	0.187	0.480
43	35068.86	18303.52	2.908	42	0.105	5.235	0.064	0.184	0.345
44	54985.70	22294.11	2.938	50	0.119	3.725	0.080	0.208	0.384
45	114858.56	30792.57	2.879	42	0.148	3.210	0.076	0.270	0.282
46	47741.17	19819.53	2.905	42	0.168	6.116	0.088	0.274	0.320
47	38789.62	20930.85	2.909	46	0.135	4.377	0.066	0.236	0.281
48	30117.71	20133.04	2.933	46	0.079	2.755	0.053	0.150	0.354
49	38873.38	22747.13	2.942	52	0.086	3.241	0.061	0.153	0.397
50	27906.08	18491.42	2.932	50	0.077	4.204	0.063	0.107	0.584
51	51473.08	23199.40	2.883	46	0.143	4.592	0.078	0.304	0.256
52	46688.52	21980.89	2.905	60	0.103	4.605	0.067	0.171	0.390
53	48673.60	21783.15	2.898	54	0.115	4.552	0.078	0.156	0.502
54	25041.14	15823.34	2.810	34	0.111	7.097	0.094	0.149	0.632
55	66201.89	27774.81	2.884	56	0.112	3.060	0.044	0.228	0.191
56	31007.15	12559.91	2.889	58	0.130	3.719	0.078	0.159	0.489
57	59584.40	23908.65	2.917	38	0.137	6.168	0.098	0.188	0.520
58	39890.73	18699.87	2.868	56	0.086	3.025	0.025	0.180	0.138
59	35361.85	17590.80	2.833	58	0.116	2.954	0.063	0.167	0.376
60	46443.75	20434.26	2.873	76	0.103	2.191	0.059	0.089	0.658
61	100138.48	28636.29	2.896	80	0.103	2.342	0.076	0.100	0.761
62	54433.75	22669.64	2.921	70	0.109	2.356	0.101	0.090	1.125
63	39708.55	16933.43	2.897	38	0.183	4.468	0.132	0.206	0.638
64	34707.45	19171.80	2.919	44	0.110	4.693	0.085	0.160	0.530
65	32868.05	18322.80	2.910	42	0.128	6.382	0.085	0.263	0.325
66	42038.15	20730.86	2.894	40	0.132	4.609	0.092	0.214	0.429
67	53150.04	25816.83	2.920	46	0.118	4.234	0.082	0.196	0.417
68	44801.78	18356.35	2.852	56	0.130	5.146	0.058	0.223	0.261
69	48741.49	22398.78	2.906	38	0.185	6.512	0.091	0.377	0.242
70	29616.81	16586.56	2.884	48	0.126	5.515	0.086	0.201	0.428
71	53314.38	21014.08	2.905	46	0.097	5.207	0.045	0.136	0.327
72	52007.39	20752.07	2.914	60	0.126	3.862	0.126	0.050	2.543
73	55791.54	20783.99	2.869	42	0.160	5.524	0.095	0.306	0.309
74	79005.11	26259.79	2.866	46	0.170	4.253	0.101	0.235	0.428
75	85179.33	26534.52	2.856	56	0.139	4.153	0.089	0.188	0.474
76	71715.82	25678.43	2.909	56	0.135	3.311	0.096	0.163	0.592
77	96376.07	29436.72	2.936	60	0.124	2.835	0.099	0.165	0.598
78	42266.44	21314.09	2.930	62	0.134	2.674	0.122	0.160	0.759
79	95792.89	29060.96	2.917	60	0.111	2.146	0.111	0.133	0.837
80	15858.98	5355.16	2.610	68	0.095	2.434	0.113	0.089	1.276
81	43812.06	20006.59	2.952	58	0.085	2.621	0.118	0.032	3.670

Post-Hurricane

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
1	15230.13	15365.08	2.907	44	0.088	2.558	0.108	0.043	2.499
2	60773.35	23960.33	2.924	54	0.106	2.778	0.104	0.061	1.706
3	45434.24	20547.24	2.893	46	0.100	3.839	0.102	0.038	2.689
4	40977.34	19432.31	2.937	46	0.117	4.045	0.104	0.119	0.871
5	51775.38	22618.57	2.943	42	0.107	3.517	0.079	0.124	0.641
6	18997.25	12600.55	2.959	46	0.111	2.802	0.116	0.033	3.510
7	17888.11	13783.96	2.884	58	0.091	2.204	0.108	-0.01	-14.21
8	9743.60	11518.56	2.853	50	0.089	2.096	0.129	0.104	1.241
9	8414.81	11700.90	2.898	36	0.093	4.071	0.070	0.100	0.706
10	9519.42	12116.57	2.919	30	0.073	7.411	0.066	0.074	0.891
11	12220.03	13530.62	2.919	26	0.064	10.369	0.068	0.056	1.207
12	60169.45	23113.01	2.904	34	0.049	5.461	0.057	0.028	2.016
13	24785.27	18610.77	2.894	30	0.077	5.820	0.067	0.091	0.732
14	31919.47	21032.72	2.883	34	0.102	6.482	0.063	0.175	0.363
15	8914.69	11188.17	2.911	48	0.108	5.238	0.057	0.177	0.320
16	8855.29	11549.66	2.882	42	0.117	5.271	0.065	0.170	0.384
17	26619.54	17796.76	2.855	32	0.060	5.917	0.065	0.053	1.213
18	22001.78	16348.87	2.817	32	0.057	6.374	0.064	0.046	1.403
19	21064.96	16346.75	2.845	40	0.125	5.752	0.073	0.200	0.364
20	17987.45	14335.46	2.876	34	0.100	5.627	0.077	0.160	0.479
21	17024.77	15392.73	2.866	38	0.100	4.784	0.073	0.188	0.389
22	14770.85	15537.97	2.829	34	0.067	5.330	0.080	0.051	1.561
23	26413.58	16871.85	2.927	32	0.120	8.912	0.070	0.245	0.286
24	28693.37	21740.18	2.809	38	0.070	6.518	0.053	0.089	0.596
25	50028.26	27560.26	2.864	42	0.100	5.891	0.056	0.175	0.318
26	27636.27	24236.77	2.884	54	0.215	4.455	0.044	0.226	0.193
27	25099.41	23892.59	2.944	50	0.059	2.269	0.031	0.125	0.247
28	36704.50	28778.51	2.958	52	0.048	2.729	0.036	0.075	0.478
29	41502.75	27778.37	2.921	60	0.047	2.157	0.035	0.053	0.663
30	32054.50	27533.96	2.898	70	0.041	1.111	0.045	0.030	1.483
31	23931.34	21233.69	2.885	64	0.042	0.870	0.022	0.084	0.263
32	28932.62	21075.18	2.855	50	0.069	2.779	0.041	0.123	0.335
33	23187.10	16234.06	2.842	44	0.051	2.055	0.064	0.063	1.026
34	26298.85	17589.99	2.915	44	0.067	2.650	0.057	0.106	0.537
35	39867.40	25918.80	2.931	50	0.066	3.046	0.069	0.075	0.921
36	48738.73	24767.36	2.906	56	0.107	2.633	0.064	0.201	0.317
37	48640.10	23571.46	2.909	58	0.123	2.174	0.065	0.198	0.327
38	37023.65	20081.32	2.916	44	0.140	2.415	0.086	0.252	0.340
39	26044.31	16805.97	2.914	42	0.100	2.318	0.087	0.118	0.733
40	29130.69	16543.12	2.886	36	0.134	3.599	0.094	0.203	0.462
41	15236.94	11518.39	2.789	36	0.099	7.475	0.104	0.051	2.025
42	20657.78	15324.59	2.934	30	0.124	7.604	0.096	0.162	0.594

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
43	24697.97	14539.31	2.880	32	0.104	6.900	0.100	0.110	0.910
44	35492.32	17411.58	2.907	36	0.146	4.389	0.107	0.195	0.547
45	88029.74	29217.48	2.884	34	0.183	4.730	0.106	0.322	0.330
46	29035.94	17016.73	2.885	36	0.154	4.689	0.101	0.199	0.510
47	29004.62	16919.80	2.937	40	0.136	4.522	0.100	0.211	0.475
48	17223.17	12720.09	2.911	34	0.076	4.647	0.112	0.028	4.001
49	18917.13	15340.64	2.891	18	0.077	5.807	0.077	0.087	0.884
50	11851.74	12798.79	2.867	34	0.062	6.998	0.076	0.050	1.510
51	25498.30	19806.76	2.855	40	0.104	6.488	0.057	0.207	0.276
52	18146.80	16270.79	2.877	42	0.126	6.780	0.059	0.271	0.216
53	20401.32	14625.85	2.845	38	0.126	6.469	0.087	-0.001	-147.7
54	9741.12	9858.08	2.950	24	0.097	11.860	0.102	0.107	0.946
55	34548.74	17786.22	2.862	34	0.169	9.191	0.085	0.247	0.344
56	23593.00	11304.42	2.900	44	0.144	5.203	0.076	0.191	0.396
57	24483.74	16785.94	2.875	30	0.075	6.745	0.065	0.090	0.724
58	13581.75	14701.52	2.910	36	0.100	6.583	0.065	0.143	0.453
59	16877.32	13565.24	2.864	50	0.104	4.266	0.074	0.158	0.468
60	32758.86	19616.60	2.898	66	0.110	2.832	0.068	0.121	0.564
61	76761.49	27885.46	2.858	68	0.109	2.815	0.092	0.092	1.003
62	31646.11	20015.68	2.932	66	0.095	2.903	0.078	0.148	0.525
63	26634.92	18570.88	2.941	40	0.080	2.579	0.078	0.087	0.889
64	19694.38	15090.26	2.951	38	0.086	7.012	0.084	0.069	1.217
65	20373.72	15030.54	2.925	36	0.083	4.844	0.083	0.083	1.007
66	27163.43	17783.43	2.859	36	0.093	4.968	0.088	0.104	0.848
67	33176.53	21994.19	2.910	38	0.098	5.021	0.087	0.121	0.723
68	19798.95	13839.90	2.925	42	0.109	5.739	0.092	0.131	0.703
69	20577.03	15029.55	2.878	16	0.124	9.401	0.095	0.182	0.519
70	16317.96	13201.81	2.961	34	0.130	6.493	0.097	0.199	0.488
71	29943.52	17115.16	2.934	30	0.098	7.151	0.091	0.117	0.780
72	25171.26	15179.17	2.903	54	0.116	4.312	0.092	0.107	0.861
73	39000.79	18118.40	2.894	32	0.163	6.777	0.091	0.309	0.295
74	44779.93	20037.34	2.887	40	0.172	5.231	0.099	0.279	0.354
75	54604.91	21164.18	2.862	42	0.165	5.424	0.104	0.227	0.457
76	46455.84	20759.63	2.901	46	0.154	5.522	0.096	0.191	0.502
77	60533.28	23897.68	2.913	46	0.128	3.785	0.103	0.133	0.777
78	19153.99	13916.79	2.807	52	0.148	3.052	0.099	0.178	0.556
79	61536.73	23355.78	2.822	50	0.132	3.507	0.094	0.152	0.617
80	10660.11	4424.97	2.821	58	0.102	2.882	0.102	0.106	0.963
81	34384.54	18346.12	2.949	48	0.099	4.173	0.100	0.092	1.085

Recovery Period

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
1	25895.35	15457.82	2.893	46	0.089	3.782	0.139	0.020	6.791
2	66807.60	23511.44	2.902	52	0.112	2.425	0.143	0.070	2.038
3	51020.80	20388.29	2.859	46	0.103	3.465	0.138	0.018	7.510
4	46204.20	18311.96	2.883	46	0.117	4.111	0.132	0.082	1.604
5	56705.15	21312.07	2.908	44	0.112	3.572	0.119	0.083	1.429
6	22454.56	12559.98	2.953	48	0.109	3.214	0.155	-0.004	-38.30
7	23749.55	12974.37	2.842	56	0.088	2.364	0.164	-0.027	-6.094
8	20801.27	13477.76	2.880	50	0.096	2.172	0.166	0.060	2.767
9	18412.27	13450.23	2.824	34	0.125	4.222	0.127	0.085	1.508
10	18830.35	13082.14	2.793	32	0.104	5.185	0.127	0.036	3.527
11	22016.08	14830.47	2.844	28	0.111	5.977	0.117	0.098	1.185
12	64531.51	23119.57	2.817	36	0.082	4.718	0.098	0.054	1.823
13	37882.49	18422.47	2.809	34	0.114	6.787	0.105	0.135	0.779
14	47958.19	21738.65	2.773	36	0.138	6.591	0.103	0.200	0.514
15	18026.37	14058.51	2.839	48	0.119	5.166	0.097	0.106	0.918
16	17259.46	13079.60	2.780	46	0.123	4.142	0.102	0.127	0.800
17	35987.26	18304.64	2.792	38	0.077	5.019	0.083	0.047	1.764
18	32544.09	18823.39	2.806	36	0.094	5.764	0.092	0.087	1.063
19	30882.84	17401.12	2.833	42	0.128	5.346	0.100	0.145	0.690
20	30517.58	16550.60	2.852	40	0.112	5.965	0.100	0.145	0.693
21	37641.83	19334.57	2.912	42	0.121	6.454	0.104	0.158	0.659
22	36944.18	19499.44	2.838	38	0.100	4.543	0.099	0.112	0.886
23	30042.62	16358.85	2.864	40	0.118	5.495	0.116	0.150	0.776
24	58990.87	27268.69	2.900	46	0.086	4.610	0.107	0.096	1.117
25	76733.82	30392.72	2.922	56	0.085	3.532	0.086	0.115	0.750
26	50453.25	25934.55	2.900	62	0.160	2.641	0.103	0.145	0.711
27	51752.96	25378.71	2.847	54	0.060	2.281	0.114	0.034	3.331
28	60393.29	30550.07	2.781	54	0.049	1.923	0.116	0.002	56.20
29	45995.73	23102.94	2.855	64	0.051	2.240	0.087	0.020	4.278
30	45108.78	23587.16	2.841	58	0.049	1.540	0.095	0.033	2.875
31	44804.46	23184.61	2.876	56	0.064	2.176	0.109	0.043	2.551
32	46949.62	24441.58	2.914	54	0.065	2.185	0.109	0.064	1.695
33	41228.23	21350.54	2.855	52	0.056	1.977	0.104	0.022	4.779
34	26251.13	15654.49	2.865	56	0.061	1.867	0.089	0.040	2.224
35	60662.68	30358.25	2.904	58	0.059	2.141	0.093	0.043	2.146
36	63657.57	27512.32	2.897	64	0.092	2.179	0.090	0.150	0.602
37	60398.62	24827.92	2.903	64	0.112	1.629	0.086	0.172	0.499
38	44133.57	20692.70	2.908	46	0.144	2.531	0.110	0.218	0.503
39	31577.52	17742.39	2.854	46	0.111	2.354	0.084	0.125	0.671
40	29192.55	13932.65	2.830	32	0.190	5.231	0.120	0.212	0.566
41	14418.96	10923.96	2.679	42	0.111	5.439	0.083	0.127	0.652
42	22308.36	15378.02	2.747	28	0.161	9.114	0.089	0.246	0.362

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
43	26592.97	14520.55	2.859	32	0.117	6.199	0.102	0.128	0.793
44	36479.72	16983.05	2.874	40	0.150	5.519	0.094	0.190	0.494
45	86631.56	24984.75	2.854	34	0.193	5.817	0.123	0.285	0.432
46	28464.23	15606.64	2.897	36	0.174	7.180	0.119	0.228	0.522
47	28414.94	15206.23	2.843	36	0.154	5.625	0.126	0.144	0.879
48	17556.50	12068.39	2.908	32	0.111	5.452	0.128	0.062	2.073
49	28343.89	16434.25	2.777	38	0.099	5.284	0.098	0.076	1.280
50	19442.52	13028.21	2.656	34	0.097	5.849	0.098	0.076	1.288
51	32613.19	17862.95	2.861	36	0.125	6.565	0.115	0.162	0.712
52	28819.24	15534.47	2.802	40	0.143	5.822	0.113	0.209	0.542
53	32517.70	15855.51	2.835	48	0.105	7.746	0.089	0.079	1.121
54	16570.69	11782.79	2.722	28	0.118	9.069	0.111	0.130	0.852
55	44937.95	18041.93	2.889	34	0.196	7.742	0.130	0.229	0.569
56	27530.52	11267.35	2.875	46	0.155	5.023	0.117	0.138	0.848
57	36534.21	17336.93	2.782	34	0.112	7.013	0.105	0.096	1.085
58	25858.94	16140.84	2.803	30	0.147	8.887	0.119	0.159	0.748
59	17358.93	10840.18	2.853	44	0.136	4.905	0.098	0.173	0.564
60	30541.02	16141.15	2.796	60	0.126	3.540	0.107	0.109	0.974
61	78331.57	24618.45	2.839	62	0.120	3.490	0.136	0.067	2.028
62	30797.25	16446.74	2.808	62	0.118	3.894	0.114	0.138	0.829
63	25356.05	15626.22	2.831	36	0.147	5.253	0.108	0.226	0.478
64	13943.12	11318.76	2.875	30	0.142	7.376	0.117	0.177	0.657
65	14901.78	11342.72	2.771	28	0.136	8.354	0.112	0.171	0.655
66	31763.26	17732.08	2.807	32	0.153	7.455	0.112	0.222	0.502
67	44983.64	21819.15	2.886	38	0.125	5.971	0.109	0.171	0.638
68	25989.55	15214.95	2.882	40	0.128	5.541	0.109	0.130	0.837
69	24523.73	15244.58	2.881	34	0.143	7.714	0.120	0.230	0.523
70	14811.21	11552.81	2.782	36	0.155	9.111	0.104	0.209	0.499
71	30502.48	15076.37	2.811	36	0.087	8.461	0.052	0.129	0.402
72	30689.64	14816.08	2.862	52	0.129	4.949	0.113	0.102	1.106
73	40200.27	16657.87	2.786	32	0.184	7.690	0.120	0.276	0.436
74	45942.43	18729.41	2.831	38	0.194	5.710	0.115	0.287	0.402
75	52887.24	18746.84	2.831	46	0.162	5.940	0.085	0.244	0.346
76	51722.76	21546.23	2.749	40	0.188	5.469	0.121	0.193	0.626
77	64579.34	23306.02	2.821	58	0.112	3.784	0.060	0.157	0.384
78	23720.11	14728.47	2.716	52	0.149	3.231	0.123	0.165	0.747
79	66028.67	22900.11	2.815	50	0.137	3.865	0.119	0.140	0.849
80	11060.83	4241.25	2.702	58	0.105	2.972	0.108	0.087	1.249
81	38258.62	18636.21	2.938	46	0.107	3.788	0.119	0.081	1.468

<u>Canaveral National Seashore</u>

Pre-Hurricane

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
1	16221.15	8440.08	2.925	48	0.094	1.683	0.045	0.184	0.242
2	21876.68	18217.64	2.873	40	0.041	1.869	0.042	0.020	2.065
3	16985.63	17898.26	2.868	48	0.043	2.773	0.045	0.062	0.722
4	8443.69	9244.71	2.749	48	0.107	2.367	0.052	0.190	0.275
5	17970.50	15821.58	2.861	54	0.107	1.868	0.041	0.203	0.203
6	25345.00	21301.55	2.904	48	0.070	2.036	0.036	0.121	0.295
7	20319.79	17003.03	2.871	48	0.129	2.685	0.053	0.191	0.276
8	14283.23	13090.56	2.861	46	0.087	2.825	0.041	0.208	0.197
9	21418.60	18803.64	2.817	50	0.077	1.906	0.043	0.131	0.326
10	11484.61	10073.47	2.873	48	0.077	2.532	0.036	0.154	0.230
11	12047.21	10367.53	2.867	42	0.067	2.958	0.037	0.142	0.259
12	27088.38	24305.71	2.918	40	0.098	4.299	0.049	0.183	0.270
13	14977.07	10884.51	2.837	44	0.100	3.351	0.051	0.196	0.258
14	33004.82	20087.52	2.918	38	0.109	3.836	0.050	0.244	0.206
15	15464.01	8433.98	2.813	38	0.097	4.307	0.061	0.236	0.257
16	23227.37	10987.03	2.886	32	0.129	5.184	0.070	0.249	0.282
17	46440.84	24697.23	2.945	32	0.130	4.262	0.080	0.238	0.335
18	20665.05	10634.86	2.950	34	0.137	4.320	0.072	0.245	0.293
19	14261.18	7800.99	2.869	38	0.142	4.135	0.077	0.224	0.345
20	34454.55	18526.72	2.980	40	0.139	2.716	0.099	0.157	0.633
21	27982.80	15492.08	2.945	40	0.135	1.714	0.087	0.182	0.476
22	24283.57	14131.59	2.905	40	0.124	1.122	0.086	0.149	0.578
23	11554.65	14585.32	2.856	40	0.120	1.747	0.101	0.122	0.825
24	24510.16	14717.79	2.910	38	0.119	1.449	0.104	0.114	0.917
25	26140.41	13546.24	2.890	32	0.129	1.961	0.122	0.149	0.820
26	31434.62	16909.88	2.908	36	0.123	1.889	0.119	0.124	0.960
27	19873.80	11570.24	2.830	38	0.128	1.827	0.118	0.127	0.926
28	53999.43	28839.68	2.971	38	0.130	2.176	0.100	0.139	0.721
29	30337.64	15579.28	2.913	38	0.123	2.557	0.078	0.155	0.500
30	22324.34	11280.77	2.880	44	0.118	1.841	0.075	0.129	0.583
31	20262.90	13007.18	2.938	40	0.140	2.304	0.096	0.162	0.594
32	12014.94	7433.88	2.913	40	0.126	2.190	0.103	0.107	0.965
33	7648.58	6144.55	2.929	48	0.126	2.054	0.101	0.100	1.003
34	8091.10	10451.77	2.908	40	0.137	1.610	0.105	0.131	0.797
35	6835.96	5065.53	2.950	36	0.144	2.496	0.104	0.128	0.813
36	13145.08	7013.67	2.940	40	0.110	0.550	0.081	0.137	0.586
37	10514.85	6389.58	2.938	28	0.114	0.208	0.089	0.114	0.777
38	17232.03	9633.04	2.988	18	0.080	0.106	0.065	0.104	0.629
39	11955.03	7549.29	2.964	20	0.092	0.109	0.054	0.145	0.374
40	13473.40	7119.59	2.930	22	0.120	0.167	0.118	0.100	1.182

Segment	Volume	Surface Area	Fractal Dimension	Width	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
41	10073.96	6940.18	2.943	24	0.099	0.121	0.051	0.156	0.325
42	13751.87	7754.68	2.961	26	0.089	0.124	0.051	0.125	0.408
43	11546.01	7271.94	2.810	28	0.090	0.209	0.083	0.112	0.736
44	11770.01	7524.14	2.961	24	0.135	0.158	0.097	0.165	0.584
45	16712.00	14048.59	2.850	24	0.084	0.173	0.075	0.112	0.673
46	9781.58	5835.41	2.943	26	0.115	0.162	0.091	0.167	0.545
47	10996.23	6364.52	2.938	22	0.097	0.150	0.077	0.134	0.572
48	7959.14	4760.92	2.917	24	0.066	0.095	0.042	0.085	0.494
65	11425.03	7236.24	2.896	34	0.069	0.949	0.098	0.045	2.169
66	15249.08	10446.64	2.843	28	0.084	2.456	0.125	0.025	4.948
67	13619.52	14753.03	2.864	28	0.106	2.527	0.162	0.069	2.340
68	16235.82	11544.16	2.918	34	0.086	2.263	0.121	0.035	3.453
69	17240.44	11220.68	2.966	40	0.071	0.293	0.052	0.070	0.743
70	18045.12	13326.67	2.852	40	0.043	0.148	0.044	0.021	2.130
71	14469.14	10107.91	2.907	40	0.058	1.268	0.075	0.049	1.551
72	13051.16	10523.96	2.943	44	0.043	0.744	0.079	0.040	1.979
73	16756.92	14223.18	2.962	32	0.048	1.165	0.086	0.029	3.001
74	7133.45	6161.43	2.858	38	0.049	1.958	0.076	0.059	1.291
75	12014.12	9951.76	2.795	34	0.073	2.766	0.093	0.093	0.992
76	17539.53	11936.74	2.925	36	0.062	2.490	0.081	0.035	2.319
77	15786.19	11447.47	2.908	36	0.072	2.308	0.096	0.036	2.658
78	23845.53	16576.80	2.865	40	0.065	1.106	0.076	0.048	1.580
79	13298.95	10853.45	2.896	40	0.060	1.691	0.079	0.047	1.663
80	11572.62	9614.46	2.932	32	0.075	1.401	0.101	0.062	1.637
81	13875.12	10269.66	2.938	34	0.059	0.733	0.075	0.047	1.604
82	16431.14	11195.19	2.936	30	0.084	0.922	0.104	0.059	1.745
83	21900.56	12652.31	2.904	36	0.098	1.224	0.111	0.094	1.185
84	16500.07	9877.88	2.941	36	0.079	0.856	0.111	0.056	1.983
85	23303.72	13717.05	2.953	38	0.085	1.782	0.122	0.048	2.524
86	17740.23	11994.36	2.882	30	0.082	1.694	0.127	0.033	3.830
87	5218.28	5789.22	2.743	24	0.081	2.163	0.088	0.100	0.878
88	6138.27	6542.10	2.880	22	0.098	2.687	0.096	0.094	1.019
89	21418.60	18803.64	2.870	28	0.081	2.263	0.091	0.060	1.520
90	10186.79	9154.32	2.795	26	0.072	0.206	0.104	0.041	2.573
91	13416.51	9027.52	2.736	18	0.121	3.372	0.131	0.075	1.745
92	6100.02	6281.02	2.882	28	0.038	0.112	0.079	0.003	26.448
93	8914.88	4566.95	2.850	24	0.047	0.048	0.030	0.107	0.280

Post-Hurricane

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
1	60.15	6391.11	2.937	20	0.145	6.206	0.172	-0.023	-7.534
2	13258.85	17946.45	2.844	24	0.054	6.446	0.084	-0.006	-14.88
3	11635.04	19500.64	2.845	26	0.049	4.858	0.063	0.144	0.438
4	6687.17	10722.28	2.660	32	0.129	5.127	0.115	0.129	0.894
5	14176.61	21798.23	2.843	28	0.122	4.496	0.123	0.090	1.375
6	17993.54	26408.43	2.878	26	0.110	4.903	0.132	0.056	2.346
7	13239.52	25046.97	2.829	44	0.110	3.264	0.095	0.123	0.778
8	12517.49	18794.46	2.777	32	0.126	4.185	0.116	0.115	1.011
9	10146.14	15030.18	2.753	40	0.094	3.451	0.071	0.100	0.711
10	9335.06	17206.01	2.810	38	0.089	4.065	0.067	0.092	0.729
11	8461.26	15189.86	2.854	28	0.113	3.856	0.111	0.120	0.923
12	6227.25	22531.77	2.937	32	0.127	4.935	0.110	0.132	0.836
13	6392.02	15814.88	2.880	30	0.117	4.814	0.137	0.084	1.641
14	7277.79	24009.85	2.963	30	0.115	5.217	0.090	0.137	0.655
15	4229.71	8291.43	2.829	30	0.100	4.130	0.102	0.077	1.315
16	10194.99	9972.17	2.854	30	0.103	4.070	0.088	0.122	0.721
17	21346.72	25977.00	2.954	28	0.123	4.857	0.133	0.105	1.268
18	10763.16	9376.62	2.867	24	0.138	4.165	0.174	0.055	3.176
19	11144.80	8180.57	2.852	24	0.174	6.271	0.160	0.117	1.367
20	19747.09	18066.34	2.935	22	0.131	4.992	0.227	0.059	3.834
21	17753.09	14305.62	2.892	22	0.177	3.973	0.239	0.086	2.796
22	15396.03	14381.61	2.933	24	0.169	3.327	0.221	0.118	1.873
23	1947.55	18530.60	2.867	32	0.140	3.933	0.097	0.109	0.886
24	17313.21	15115.66	2.934	28	0.144	2.779	0.173	0.118	1.463
25	15877.50	14061.04	2.856	28	0.125	1.620	0.150	0.108	1.388
26	21507.27	16841.40	2.882	30	0.140	2.901	0.159	0.099	1.612
27	14593.35	12041.66	2.802	34	0.146	2.964	0.131	0.130	1.005
28	34780.22	29743.17	2.977	32	0.154	3.493	0.173	0.101	1.715
29	17159.03	15223.72	2.912	26	0.161	2.964	0.188	0.144	1.310
30	13423.00	13389.43	2.795	38	0.119	2.846	0.115	0.092	1.245
31	5920.17	12112.64	2.910	40	0.113	2.209	0.077	0.130	0.592
32	281.00	5958.72	2.922	40	0.099	2.089	0.113	0.047	2.387
33	1276.41	4269.27	2.823	46	0.099	3.198	0.092	0.062	1.478
34	1127.73	13255.23	2.876	46	0.097	0.657	0.058	0.082	0.715
35	49.96	3414.51	2.969	34	0.097	2.512	0.111	0.052	2.159
36	610.39	5202.32	2.971	28	0.107	3.800	0.122	0.036	3.424
37	946.73	4832.83	2.967	8	-0.045	NA	NA	NA	NA
38	720.63	7590.81	2.972	18	0.102	1.850	0.044	0.150	0.292
39	756.19	5525.07	2.925	10	0.009	0.571	0.046	-0.054	-0.853
40	549.92	5212.09	2.982	14	0.092	2.381	0.141	0.087	1.622
41	251.04	5105.66	2.951	12	0.168	4.443	0.254	0.101	2.516
42	933.50	5925.76	2.948	16	0.119	3.067	0.043	0.185	0.230

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
43	1174.42	5877.35	2.960	14	0.137	2.683	0.142	0.319	0.446
44	1129.63	5857.25	2.897	10	0.122	2.833	0.119	0.000	0.000
45	4406.74	16675.08	2.864	12	0.127	2.965	0.022	0.147	0.149
46	652.45	3669.33	2.854	18	0.100	2.616	0.091	0.171	0.533
47	1366.47	4843.12	2.954	14	0.112	3.272	0.102	0.038	2.708
48	914.24	5374.87	2.974	14	0.072	3.392	0.161	-0.152	-1.059
65	5107.06	9750.93	2.887	24	0.044	3.558	0.018	0.055	0.328
66	6290.19	11331.45	2.824	34	0.039	2.323	0.042	0.024	1.759
67	6175.56	14412.60	2.836	26	0.060	2.384	0.096	0.015	6.435
68	7683.34	10945.45	2.837	32	0.056	2.290	0.061	0.035	1.766
69	4246.18	9101.25	2.904	40	0.048	0.456	0.046	0.041	1.139
70	3151.22	14336.32	2.860	40	0.037	0.419	0.041	0.013	3.010
71	3045.35	8585.74	2.765	32	0.033	2.705	0.051	0.016	3.211
72	1093.87	10276.80	2.898	46	0.020	0.527	0.038	0.017	2.230
73	4284.45	17480.41	2.955	34	0.024	2.193	0.019	0.015	1.282
74	1680.70	8715.85	2.783	36	0.041	3.082	0.046	0.022	2.071
75	4198.77	14857.24	2.873	22	0.096	5.462	0.114	0.062	1.841
76	3250.43	13671.02	2.878	32	0.068	4.578	0.098	0.040	2.427
77	5260.26	10590.84	2.836	32	0.055	4.172	0.034	0.056	0.599
78	16575.28	17917.26	2.865	30	0.045	1.690	0.060	0.006	10.246
79	5369.30	10207.04	2.921	34	0.054	2.341	0.076	0.028	2.733
80	2780.30	9382.71	2.912	24	0.080	3.272	0.097	0.039	2.516
81	1098.68	8444.60	2.959	18	0.076	4.736	0.081	0.045	1.814
82	4537.46	9730.50	2.933	24	0.064	1.921	0.066	0.035	1.890
83	13225.46	11573.58	2.930	32	0.133	2.319	0.113	0.128	0.887
84	4125.65	8852.12	2.875	22	0.123	3.001	0.114	0.108	1.057
85	10874.44	14516.72	2.899	32	0.127	3.166	0.123	0.109	1.129
86	1302.65	14424.46	2.930	24	0.053	3.399	0.041	0.101	0.402
87	234.18	7400.26	2.900	6	0.195	NA	NA	NA	NA
88	893.45	8292.03	2.881	18	0.056	3.863	0.032	0.031	1.030
89	13958.29	20595.39	2.854	18	0.160	3.685	0.159	0.130	1.218
90	1072.93	8028.07	2.945	12	0.082	2.997	0.138	0.041	3.342
91	374.36	7303.63	2.939	12	0.129	7.238	0.030	0.022	1.324
92	234.73	9500.10	2.954	2	NA	NA	NA	NA	NA
93	50.74	455.41	2.957	4	NA	NA	NA	NA	NA

Recovery Period

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
1	16620.30	8471.24	2.932	42	0.111	2.142	0.119	0.122	0.976
2	32826.35	16502.79	2.927	42	0.061	2.158	0.103	0.012	8.937
3	29118.29	15911.34	2.913	48	0.061	2.258	0.084	0.041	2.058
4	15049.30	8184.28	2.846	48	0.107	2.254	0.095	0.163	0.580
5	29968.63	16160.05	2.903	46	0.120	1.911	0.102	0.186	0.548
6	34975.08	20084.48	2.926	38	0.095	2.286	0.121	0.083	1.461
7	26384.16	15462.56	2.916	46	0.126	1.955	0.107	0.147	0.726
8	19239.73	12580.79	2.882	40	0.113	2.675	0.118	0.152	0.775
9	11761.54	8538.83	2.870	50	0.086	2.216	0.095	0.083	1.136
10	13252.81	9804.80	2.913	44	0.095	3.457	0.098	0.117	0.844
11	15116.53	11342.11	2.913	38	0.100	4.361	0.114	0.097	1.184
12	41762.94	20633.68	2.927	40	0.108	3.285	0.109	0.130	0.840
13	19014.06	12087.88	2.891	42	0.112	3.168	0.096	0.154	0.626
14	34844.84	20001.83	2.927	36	0.125	4.999	0.115	0.183	0.628
15	19051.89	9064.77	2.835	36	0.117	4.141	0.096	0.168	0.574
16	24460.18	11032.74	2.855	30	0.116	4.455	0.105	0.158	0.663
17	54774.46	25573.95	2.883	32	0.107	3.889	0.104	0.111	0.938
18	25149.80	10896.29	2.895	38	0.105	3.420	0.087	0.132	0.658
19	18204.71	9155.79	2.834	40	0.104	2.291	0.091	0.118	0.772
20	39853.37	18803.18	2.901	40	0.125	2.238	0.103	0.138	0.743
21	32274.75	15456.69	2.938	44	0.118	0.531	0.101	0.174	0.576
22	26916.92	13338.41	2.907	42	0.130	0.462	0.089	0.166	0.534
23	22186.41	14148.29	2.940	44	0.116	1.512	0.103	0.133	0.772
24	29225.75	14939.60	2.907	40	0.108	0.320	0.097	0.130	0.745
25	26968.01	13564.26	2.871	40	0.111	0.587	0.104	0.137	0.755
26	35326.64	16168.39	2.904	40	0.117	0.349	0.073	0.152	0.478
27	25888.58	12067.10	2.888	40	0.127	2.041	0.118	0.153	0.772
28	65619.51	29033.33	2.945	36	0.136	1.809	0.124	0.172	0.722
29	31231.24	14287.32	2.933	38	0.121	2.547	0.105	0.169	0.623
30	28333.24	12348.93	2.915	44	0.122	1.582	0.080	0.160	0.502
31	22961.35	12693.06	2.886	40	0.153	2.029	0.105	0.209	0.503
32	11355.79	7414.36	2.848	42	0.127	1.693	0.116	0.121	0.953
33	7689.98	5604.83	2.508	52	0.118	1.332	0.091	0.108	0.846
34	13736.52	9305.86	2.858	38	0.154	1.960	0.133	0.150	0.890
35	6899.43	5069.28	2.723	38	0.134	1.909	0.135	0.105	1.286
36	13572.32	6985.35	2.850	36	0.120	1.379	0.123	0.097	1.263
37	7272.84	6312.27	2.755	28	0.130	0.353	0.126	0.154	0.822
38	14237.80	9504.26	2.854	18	0.108	0.149	0.087	0.160	0.544
39	12254.76	7326.38	2.887	20	0.110	0.189	0.119	0.113	1.050
40	14893.38	7112.96	2.941	22	0.095	0.135	0.107	0.087	1.226
41	6999.80	6544.59	2.858	24	0.111	0.282	0.098	0.128	0.769
42	10400.36	7681.06	2.933	26	0.091	0.274	0.113	0.065	1.737

Segment	Volume (m^3)	Surface Area (m^2)	Fractal Dimension	Width (m)	Overall Slope	Log Slope	Foredune Slope	Dune Slope	Slope Ratio
43	9733.54	6839.21	2.617	28	0.100	0.257	0.111	0.044	2.555
44	7098.13	6534.54	2.817	24	0.126	0.133	0.093	0.174	0.538
45	23706.56	13454.60	2.911	22	0.105	1.186	0.108	0.084	1.292
46	6080.81	5680.64	2.874	26	0.101	0.257	0.109	0.125	0.873
47	7710.55	6210.39	2.809	22	0.088	0.183	0.087	0.086	1.021
48	10067.07	7735.52	2.879	24	0.059	0.425	0.094	-0.031	-3.000
65	9231.65	6737.70	2.898	26	0.071	1.881	0.121	0.006	20.804
66	12221.45	10648.86	2.893	26	0.065	2.580	0.083	0.014	5.763
67	19529.88	11401.76	2.935	26	0.089	2.220	0.133	0.061	2.168
68	7557.05	7711.02	2.769	32	0.073	1.626	0.100	0.044	2.287
69	8825.54	8043.73	2.834	28	0.082	2.322	0.102	0.073	1.403
70	9839.93	9451.46	2.889	32	0.067	1.715	0.106	0.020	5.225
71	10021.70	8183.36	2.876	30	0.075	2.432	0.090	0.055	1.633
72	13290.15	11212.65	2.922	42	0.037	0.905	0.058	0.043	1.352
73	16076.21	14538.29	2.954	34	0.051	1.315	0.089	0.007	13.334
74	6307.27	5828.12	2.842	38	0.045	1.978	0.087	0.008	10.659
75	9705.45	9097.59	2.892	34	0.052	3.024	0.089	0.012	7.724
76	11306.57	9712.18	2.858	34	0.051	2.581	0.086	0.001	66.657
77	12123.15	10587.30	2.894	36	0.054	2.732	0.057	0.036	1.587
78	33761.46	15337.97	2.916	36	0.046	1.100	0.079	0.017	4.515
79	8984.44	8673.46	2.903	34	0.043	1.475	0.089	-0.005	-16.62
80	8586.52	8542.14	2.907	28	0.043	1.141	0.100	-0.003	-36.59
81	7338.08	8830.13	2.878	30	0.041	1.221	0.075	0.023	3.303
82	7052.98	7993.62	2.976	22	0.061	1.629	0.103	0.024	4.319
83	11119.07	10378.74	2.930	32	0.062	2.351	0.089	0.073	1.218
84	8988.23	8361.86	2.912	32	0.052	1.647	0.100	0.027	3.708
85	13950.81	11792.89	2.948	34	0.082	2.549	0.088	0.100	0.876
86	8876.96	11286.35	2.864	28	0.067	2.444	0.073	0.054	1.369
87	4965.16	5919.72	2.788	24	0.086	2.186	0.064	0.140	0.459
88	6818.50	6877.50	2.879	24	0.099	4.619	0.093	0.100	0.934
89	31804.22	16381.13	2.918	28	0.082	1.731	0.092	0.058	1.594
90	10258.48	8061.77	2.805	26	0.069	0.181	0.101	0.042	2.428
91	14140.58	9113.13	2.748	18	0.121	2.659	0.138	0.081	1.701
92	6879.16	6672.96	2.887	28	0.036	0.096	0.070	0.008	8.900
93	9165.49	4589.22	2.870	24	0.064	0.054	0.022	0.160	0.136

APPENDIX C: REGRESSION MODELS

Southern Brevard County 2004

Loggerhead

Model Variables	AIC	w_i
Log Slope - Upper Slope - Ratio	-213.43	0.62
Overall Slope - Upper Slope - Ratio	-212.16	0.33
Overall Slope - Upper Slope - Width	-207.08	0.03
-Upper Slope - Width	-205.13	0.01
Log Slope - Upper Slope - Width	-203.15	0.00
-Ratio - Width	-200.03	0.00
-Ratio	-199.90	0.00
Overall Slope - Upper Slope	-199.76	0.00
Log Slope - Upper Slope	-199.68	0.00
-Overall Slope - Ratio	-199.55	0.00
-Surface Area + Fractal Dimension	-198.79	0.00
-Log Slope - Width	-198.13	0.00
-Log Slope - Ratio	-198.09	0.00
-Overall Slope - Lower Slope + Ratio	-197.80	0.00
-Width	-197.77	0.00
-Surface Area - Overall Slope + Fractal Dimension	-196.98	0.00
-Surface Area - Log Slope + Fractal Dimension	-196.94	0.00
-Volume + Fractal Dimension	-196.66	0.00
Fractal Dimension	-196.65	0.00
-Upper Slope	-196.57	0.00
-Width - Overall Slope	-196.52	0.00
-Log Slope - Lower Slope - Width	-196.33	0.00
-Lower Slope - Width	-196.26	0.00
-Log Slope - Lower Slope - Ratio	-196.11	0.00
-Surface Area	-195.78	0.00
-Volume	-195.04	0.00
-Lower Slope - Upper Slope	-194.93	0.00
-Volume + Overall Slope + Fractal Dimension	-194.70	0.00
-Volume + Log Slope + Fractal Dimension	-194.67	0.00
-Overall Slope - Lower Slope - Width	-194.66	0.00
-Surface Area - Overall Slope	-193.89	0.00
-Lower Slope	-193.81	0.00
-Surface Area - Log Slope	-193.78	0.00
Log Slope	-193.74	0.00
Overall Slope	-193.47	0.00

Model Variables	AIC	w_i
-Volume + Log Slope	-193.10	0.00
-Volume + Overall Slope	-193.07	0.00
Log Slope - Lower Slope	-192.20	0.00
Overall Slope - Lower Slope	-191.91	0.00

Green Turtle

Model Variables	AIC	w_i
-Ratio - Width	-46.29	0.29
-Lower Slope - Width	-46.23	0.28
Log Slope - Lower Slope - Width	-44.24	0.10
Overall Slope - Lower Slope - Width	-44.23	0.10
-Width	-43.43	0.07
-Width - Overall Slope	-42.24	0.04
-Upper Slope - Width	-41.76	0.03
-Log Slope - Width	-41.52	0.03
-Overall Slope + Upper Slope - Width	-40.25	0.01
Log Slope - Lower Slope - Ratio	-40.09	0.01
Log Slope - Upper Slope - Width	-39.76	0.01
Log Slope - Upper Slope - Ratio	-39.13	0.01
Log Slope - Lower Slope	-38.53	0.01
Log Slope - Ratio	-38.26	0.01
-Ratio	-37.18	0.00
-Overall Slope - Ratio	-35.68	0.00
Overall Slope - Lower Slope - Ratio	-35.39	0.00
Log Slope	-35.03	0.00
-Surface Area + Log Slope	-35.01	0.00
-Volume + Log Slope	-34.82	0.00
-Surface Area + Log Slope + Fractal Dimension	-34.70	0.00
-Volume + Log Slope + Fractal Dimension	-33.80	0.00
-Overall Slope + Upper Slope - Ratio	-33.74	0.00
Log Slope - Upper Slope	-33.63	0.00
-Surface Area + Fractal Dimension	-33.42	0.00
-Surface Area	-33.07	0.00
Overall Slope - Lower Slope	-31.93	0.00
-Surface Area + Overall Slope + Fractal Dimension	-31.45	0.00
-Volume	-31.45	0.00
-Lower Slope	-31.13	0.00

Model Variables	AIC	w_i
-Surface Area + Overall Slope	-31.13	0.00
-Volume + Fractal Dimension	-30.63	0.00
-Lower Slope + Upper Slope	-30.49	0.00
-Volume + Overall Slope	-30.35	0.00
-Volume + Overall Slope + Fractal Dimension	-29.59	0.00
Upper Slope	-29.16	0.00
Fractal Dimension	-28.71	0.00
Overall Slope	-28.47	0.00
-Overall Slope + Upper Slope	-27.18	0.00

Southern Brevard County 2005

Loggerhead

Model Variables	AIC	w_i
Upper Slope + Width	-202.14	0.45
-Log Slope + Upper Slope + Width	-200.51	0.20
-Overall Slope + Upper Slope + Width	-200.17	0.17
Overall Slope - Lower Slope + Width	-199.18	0.10
Width + Overall Slope	-196.81	0.03
-Log Slope + Upper Slope	-196.57	0.03
-Log Slope + Upper Slope + Ratio	-194.59	0.01
Volume - Log Slope - Fractal Dimension	-193.13	0.00
Volume - Fractal Dimension	-192.45	0.00
Volume + Overall Slope - Fractal Dimension	-191.75	0.00
-Lower Slope + Width	-190.83	0.00
Width	-190.81	0.00
Log Slope + Width	-189.82	0.00
Log Slope - Lower Slope + Width	-189.19	0.00
-Ratio + Width	-188.82	0.00
Volume	-188.65	0.00
Volume + Overall Slope	-188.34	0.00
Surface Area - Log Slope - Fractal Dimension	-188.18	0.00
Surface Area + Overall Slope - Fractal Dimension	-187.75	0.00
Volume - Log Slope	-187.57	0.00
Surface Area - Fractal Dimension	-187.10	0.00
-Log Slope - Lower Slope	-186.71	0.00
-Log Slope	-185.39	0.00
Surface Area + Overall Slope	-185.18	0.00
Upper Slope	-185.15	0.00
-Lower Slope + Upper Slope	-184.85	0.00
-Log Slope - Lower Slope - Ratio	-184.80	0.00
Surface Area	-184.69	0.00
-Lower Slope	-184.47	0.00
Surface Area - Log Slope	-184.23	0.00
-Overall Slope + Upper Slope	-184.21	0.00
Overall Slope - Lower Slope	-184.21	0.00
-Fractal Dimension	-183.69	0.00
-Log Slope - Ratio	-183.39	0.00
Overall Slope	-182.96	0.00

Model Variables	AIC	w_i
Overall Slope - Lower Slope + Ratio	-182.30	0.00
-Overall Slope + Upper Slope + Ratio	-182.23	0.00
Ratio	-182.07	0.00
Overall Slope + Ratio	-181.12	0.00

Green Turtle

Model Variables	AIC	w_i
Volume + Overall Slope	-132.69	0.16
Overall Slope	-131.38	0.08
Volume + Overall Slope - Fractal Dimension	-130.98	0.07
Overall Slope - Ratio	-130.64	0.06
Surface Area + Overall Slope	-130.12	0.04
Volume	-129.98	0.04
Width + Overall Slope	-129.97	0.04
-Ratio	-129.91	0.04
Overall Slope - Upper Slope	-129.90	0.04
Overall Slope + Lower Slope	-129.90	0.04
Upper Slope	-129.20	0.03
Overall Slope + Lower Slope - Ratio	-129.07	0.03
Lower Slope + Upper Slope	-128.96	0.02
Overall Slope - Upper Slope - Ratio	-128.96	0.02
Lower Slope	-128.75	0.02
-Log Slope + Upper Slope - Ratio	-128.48	0.02
Volume - Fractal Dimension	-128.47	0.02
Overall Slope + Lower Slope + Width	-128.47	0.02
Overall Slope - Upper Slope + Width	-128.43	0.02
-Log Slope + Upper Slope	-128.26	0.02
Volume + Log Slope	-128.26	0.02
Surface Area + Overall Slope - Fractal Dimension	-128.17	0.02
-Log Slope - Ratio	-128.00	0.02
-Ratio - Width	-127.92	0.01
-Width	-127.64	0.01
Surface Area	-127.62	0.01
-Fractal Dimension	-127.60	0.01
-Log Slope	-127.59	0.01
Upper Slope + Width	-127.31	0.01
-Log Slope + Lower Slope - Ratio	-126.81	0.01

Model Variables	AIC	w_i
Lower Slope - Width	-126.77	0.01
-Log Slope + Upper Slope - Width	-126.76	0.01
Log Slope + Lower Slope	-126.75	0.01
Volume + Log Slope - Fractal Dimension	-126.61	0.01
-Log Slope - Width	-125.91	0.01
Surface Area - Fractal Dimension	-125.67	0.00
Surface Area - Log Slope	-125.62	0.00
-Log Slope + Lower Slope - Width	-124.81	0.00
Surface Area - Log Slope - Fractal Dimension	-123.67	0.00

Canaveral National Seashore 2004

Loggerhead

Model Variables	AIC	w_i
Overall Slope - Lower Slope	-118.87	0.18
Overall Slope + Upper Slope	-117.75	0.10
Overall Slope	-117.59	0.10
Width + Overall Slope	-117.53	0.09
Overall Slope - Lower Slope + Width	-117.48	0.09
Surface Area + Overall Slope	-116.97	0.07
Overall Slope - Lower Slope + Ratio	-116.93	0.07
Overall Slope + Upper Slope + Width	-116.83	0.07
Volume + Overall Slope	-116.78	0.06
Overall Slope + Upper Slope + Ratio	-115.75	0.04
Overall Slope - Ratio	-115.72	0.04
Volume + Overall Slope - Fractal Dimension	-115.20	0.03
Surface Area + Overall Slope - Fractal Dimension	-115.17	0.03
Lower Slope + Upper Slope	-112.93	0.01
Upper Slope	-112.06	0.01
Log Slope + Upper Slope	-111.00	0.00
Upper Slope + Width	-110.32	0.00
Log Slope + Upper Slope + Width	-109.06	0.00
Log Slope + Upper Slope - Ratio	-109.02	0.00
Volume + Log Slope	-102.78	0.00
Log Slope	-102.50	0.00
Log Slope - Ratio	-102.32	0.00
Volume + Log Slope + Fractal Dimension	-101.17	0.00
Surface Area + Log Slope	-100.73	0.00
Log Slope + Width	-100.65	0.00
Log Slope + Lower Slope	-100.53	0.00
Log Slope + Lower Slope - Ratio	-100.47	0.00
Volume	-100.36	0.00
Surface Area + Log Slope + Fractal Dimension	-99.94	0.00
Log Slope + Lower Slope + Width	-98.74	0.00
Volume - Fractal Dimension	-98.42	0.00
-Ratio	-98.11	0.00
-Ratio + Width	-97.24	0.00
Surface Area	-97.15	0.00
Width	-96.67	0.00

Model Variables	AIC	w_i
Surface Area + Fractal Dimension	-95.23	0.00
Fractal Dimension	-95.13	0.00
Lower Slope + Width	-95.04	0.00
Lower Slope	-94.96	0.00

Green Turtle

Model Variables	AIC	w_i
-Surface Area	32.83	0.19
-Volume	33.95	0.11
-Surface Area - Overall Slope	34.69	0.07
-Surface Area + Fractal Dimension	34.76	0.07
-Surface Area + Log Slope	34.83	0.07
-Volume + Fractal Dimension	35.54	0.05
-Volume - Log Slope	35.92	0.04
-Volume + Overall Slope	35.95	0.04
-Surface Area - Overall Slope + Fractal Dimension	36.58	0.03
-Surface Area + Log Slope + Fractal Dimension	36.74	0.03
Ratio	36.89	0.02
-Width	36.99	0.02
-Log Slope	37.11	0.02
-Overall Slope	37.43	0.02
-Volume + Log Slope + Fractal Dimension	37.53	0.02
-Volume - Overall Slope + Fractal Dimension	37.54	0.02
-Upper Slope	37.55	0.02
-Lower Slope	37.77	0.02
Fractal Dimension	37.79	0.02
Ratio - Width	38.31	0.01
-Log Slope + Ratio	38.45	0.01
-Width - Overall Slope	38.65	0.01
-Log Slope - Width	38.70	0.01
-Lower Slope - Width	38.76	0.01
-Overall Slope + Ratio	38.80	0.01
-Upper Slope - Width	38.90	0.01
-Log Slope - Lower Slope	39.09	0.01
-Log Slope - Upper Slope	39.10	0.01
-Overall Slope - Upper Slope	39.42	0.01
-Overall Slope + Lower Slope	39.43	0.01

Model Variables	AIC	w_i
-Lower Slope - Upper Slope	39.46	0.01
-Log Slope - Lower Slope + Ratio	40.37	0.00
-Log Slope + Upper Slope + Ratio	40.39	0.00
-Log Slope - Lower Slope - Width	40.53	0.00
-Overall Slope - Lower Slope - Width	40.58	0.00
-Overall Slope + Upper Slope - Width	40.64	0.00
-Log Slope - Upper Slope - Width	40.69	0.00
-Overall Slope - Lower Slope + Ratio	40.76	0.00
-Overall Slope + Upper Slope + Ratio	40.78	0.00

Canaveral National Seashore 2005

Loggerhead

Model Variables	AIC	w_i
-Log Slope + Lower Slope + Width	-143.19	0.34
-Log Slope + Upper Slope + Width	-142.27	0.21
Width + Overall Slope	-140.63	0.10
Upper Slope + Width	-139.99	0.07
Lower Slope + Width	-139.66	0.06
Overall Slope + Lower Slope + Width	-139.57	0.06
-Log Slope + Width	-139.22	0.05
Overall Slope + Upper Slope + Width	-138.77	0.04
-Ratio + Width	-138.46	0.03
Width	-137.48	0.02
Lower Slope + Upper Slope	-134.13	0.00
Upper Slope	-133.86	0.00
Overall Slope	-133.83	0.00
-Log Slope + Upper Slope	-133.33	0.00
Overall Slope - Ratio	-133.32	0.00
Surface Area + Overall Slope	-133.31	0.00
Volume + Overall Slope	-132.99	0.00
Overall Slope + Upper Slope	-132.50	0.00
-Log Slope + Upper Slope - Ratio	-132.29	0.00
Overall Slope + Lower Slope	-132.02	0.00
Overall Slope + Upper Slope - Ratio	-131.78	0.00
Surface Area + Overall Slope + Fractal Dimension	-131.63	0.00
Overall Slope + Lower Slope - Ratio	-131.56	0.00
Volume + Overall Slope + Fractal Dimension	-131.44	0.00
Volume	-129.49	0.00
Volume - Log Slope	-129.38	0.00
Lower Slope	-128.91	0.00
Surface Area - Log Slope	-128.63	0.00
Surface Area	-128.51	0.00
-Log Slope + Lower Slope - Ratio	-128.31	0.00
-Log Slope + Lower Slope	-128.22	0.00
-Ratio	-127.82	0.00
Volume - Fractal Dimension	-127.56	0.00
Volume - Log Slope - Fractal Dimension	-127.42	0.00
Surface Area - Log Slope - Fractal Dimension	-126.74	0.00

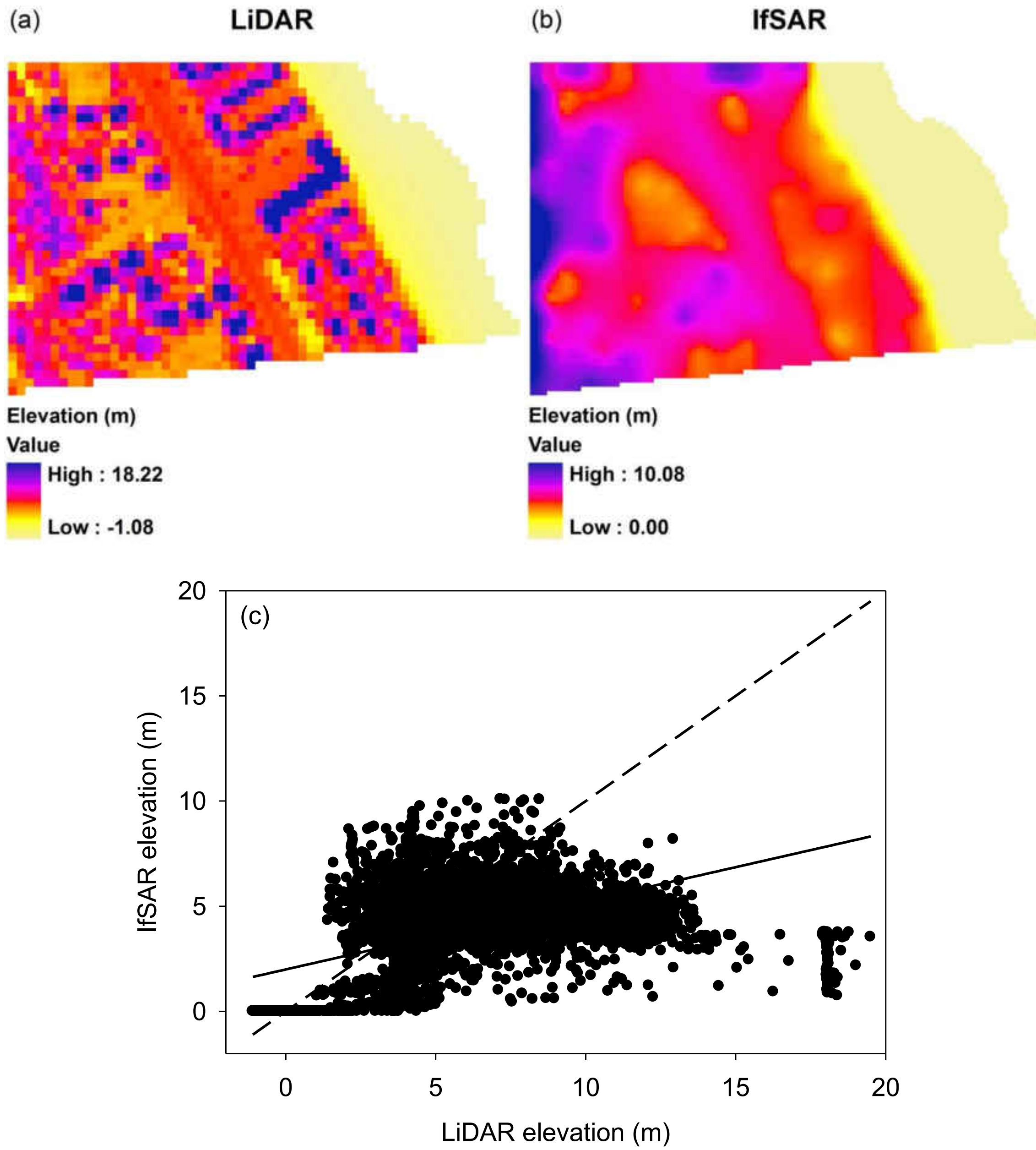
Model Variables	AIC	w_i
Surface Area - Fractal Dimension	-126.62	0.00
-Log Slope - Ratio	-126.30	0.00
-Log Slope	-125.95	0.00
Fractal Dimension	-125.54	0.00

Green Turtle

Model Variables	AIC	w_i
Upper Slope	-75.57	0.15
Upper Slope + Width	-75.46	0.14
-Overall Slope + Upper Slope	-74.53	0.09
-Overall Slope + Upper Slope + Width	-74.41	0.08
-Lower Slope + Upper Slope	-73.75	0.06
Log Slope + Upper Slope	-73.61	0.06
-Log Slope + Upper Slope + Width	-73.48	0.05
Width	-73.01	0.04
-Overall Slope + Upper Slope - Ratio	-72.78	0.04
Width + Overall Slope	-72.70	0.04
-Ratio + Width	-72.07	0.03
Log Slope + Upper Slope - Ratio	-71.92	0.02
Overall Slope	-71.90	0.02
Overall Slope - Lower Slope + Width	-71.42	0.02
Overall Slope - Lower Slope	-71.09	0.02
-Log Slope + Width	-71.01	0.02
Lower Slope + Width	-71.01	0.02
Surface Area + Overall Slope	-70.55	0.01
Overall Slope - Ratio	-70.47	0.01
Volume	-70.44	0.01
Volume + Overall Slope	-70.33	0.01
Surface Area	-70.24	0.01
-Ratio	-69.87	0.01
Overall Slope - Lower Slope - Ratio	-69.61	0.01
Log Slope	-69.09	0.01
-Log Slope + Lower Slope + Width	-69.01	0.01
-Fractal Dimension	-68.87	0.01
Lower Slope	-68.86	0.01
Volume - Fractal Dimension	-68.81	0.00
Surface Area - Fractal Dimension	-68.73	0.00

Model Variables	AIC	w_i
Surface Area + Overall Slope - Fractal Dimension	-68.60	0.00
Volume + Log Slope	-68.48	0.00
Volume + Overall Slope - Fractal Dimension	-68.34	0.00
Surface Area + Log Slope	-68.26	0.00
Log Slope - Ratio	-68.20	0.00
Log Slope - Lower Slope	-67.09	0.00
Volume + Log Slope - Fractal Dimension	-66.86	0.00
Surface Area + Log Slope - Fractal Dimension	-66.75	0.00
Log Slope - Lower Slope - Ratio	-66.21	0.00

APPENDIX D: RELATIONSHIP BETWEEN LIDAR AND IFSAR ELEVATION DATA



To better understand the differences between the LiDAR and IfSAR data, I made a comparison using the only area within range of the Canaveral National Seashore study area where both types of remote sensing data were available. This was an approximately 0.15-km^2 area just north of CNS. Due to the difference in cell resolution, I aggregated the cells of the LiDAR data (a) to match the 4.3-m spatial resolution of the IfSAR (b). I plotted the LiDAR and

IfSAR elevation data returns (c) in comparison to a line with a slope of one (dashed line) to determine if one type of remote sensing showed a bias in height. This comparison suggests that LiDAR return data tended to be higher in elevation than IfSAR data. The regression line (solid line) indicates that there is a weak but significant correlation between the two types of remote sensing data ($r^2 = 0.32$, $p < 0.0001$).

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