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Measuring the effects of morphological changes to sea turtle nesting beaches over time with LiDAR data

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ABSTRACT

Sea turtle nesting beaches in southeastern Florida were evaluated for changes from 1999 to 2005 using LiDAR datasets. Changes to beach volume were correlated with changes in several elevation-derived characteristics, such as elevation and slope. In addition, these changes to beach geomorphology were correlated to changes in nest success, illustrating that beach alterations may affect sea turtle nesting behavior. The ability to use LiDAR datasets to quickly and efficiently conduct beach comparisons for habitat use represents another benefit to this high spatial resolution data.

1. Introduction

Marine species that depend on beaches have adapted to the constant changes in beach morphology, but at some point the habitat may be altered too drastically to be available as suitable habitat. Sea turtles show strong natal homing (e.g. Green turtles, *Chelonia mydas*, Bowen et al. 1992, loggerhead, *Caretta caretta* Bowen et al. 1993). However, individuals stray from these natal beaches (Carr and Carr, 1972; Tucker, 2010; Hays and Sutherland, 1991), indicating that fidelity to the natal beach, though strong, is not absolute.

Entire populations may change nesting beach preferences, especially when changes to the beaches have caused the beach to become unsuitable for nesting activities. The year immediately following artificial beach nourishment from imported sand, *C. caretta* and *C. mydas* showed a decrease in nesting activity (Brock et al., 2009). Factors such as erosion and deposition of offshore mud banks in French Guiana can result in the complete loss of sandy beaches suitable for nesting, while changes in river paths can create new nesting areas (Kelle et al., 2007). In such dynamic areas, previously well-used nesting beaches can be abandoned, and other lesser-used beaches will suddenly support large numbers of nesting females (Kelle et al., 2007). It appears that slope, and the change of slope, in nesting beaches can also influence nesting activity. For *C. caretta,* higher nest densities are found in beaches with greater beach slopes, and for these nesting beaches, slope was inversely correlated with beach width (Provancha and Ehrhart, 1987). Mortimer (1982) hypothesized that slope and offshore configuration of the beach may be of importance to sea turtle nesting activity, although the values have been quantified.

Nesting success, or the number of successful crawls (i.e. crawls that result in a nest), divided by the total number of crawls (Brock et al., 2009) is used to determine how changes in beach morphology affect sea turtle nesting behavior. The lower the nesting success, the less suitable the nesting area, and the change in nesting success can serve as a method to establish beach suitability from one year to another (Brock et al., 2009). For a stretch of nesting beaches in Florida, post-hurricane dramatic restoration efforts (50–99% and 100% restoration) resulted in decreases in nesting success. These results were correlated with changes to beach profiles, in particular for slope and volume (Long et al., 2011). Nesting success is a preferable value to nesting numbers for beach suitability, as individual female *C. mydas* turtles most often nest every two or more years, and never consecutively (Broderick et al., 2001). Female *C. caretta*, however, can nest in subsequent years, or return every two to three years (Broderick et al., 2001).

As a result of climate change and sea level rise, the low-lying beaches used by sea turtles for nesting are at risk of inundation, which may cause the extinction of entire populations (Fish et al., 2005, Fuentes et al., 2010). In addition, warming temperatures may skew the sex ratios, as a sea turtle's gender is determined by the temperature of the sand

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surrounding its egg; warmer temperatures result in the development of females (Morreale et al., 1982; Yntema and Mrosovsky, 1980). Nesting beaches are also at risk due to increased storm intensity (Poloczanska et al., 2009). The need for additional research efforts to highlight preferred nesting area variables is of the utmost importance before current nesting areas are forever lost or the sex ratio forever altered.

Light Detection and Ranging (LIDAR) data has great promise for surveying beaches, due to its relatively low cost, continuous area that can be surveyed, and vertical and horizontal accuracy (Mason et al., 2000). Laser signals are sent as pulses from sensors onboard an aircraft to the ground below, typically in the ultraviolet (UV), visible, and near infrared (NIR) portions of the electromagnetic spectrum. The direction and time it takes for the laser pulse to return to the aircraft is measured and recorded, resulting in a series of points recording the height and orientation of objects on the ground. Aircraft are usually equipped with a Global Positioning System (GPS) to collect data geographic location data, as well as an inertial navigation data to correct for pitch, roll, and heading of the aircraft while in flight. Data obtained from LiDAR systems are obtained as a "cloud" of points, which can then be used to create accurate elevation maps. LiDAR can also be used to map seafloor topography near the shore if the water is clear (Estep et al., 1994).

The increased availability of LiDAR datasets and tools has created new methods for examining coastal changes. Effects from storm events, such as hurricanes (Pietro et al., 2008; Long et al., 2011; Sherman et al., 2013) and winter storms (Benavente et al., 2013) can now be modeled and quantified with higher spatial resolution. LiDAR data has been for comparisons over time to evaluate changes over time to barrier islands (Zhou and Xie, 2009; Lentz and Hapke, 2011; Lentz et al., 2013), and efforts to test and compare foreshore dune movement models illustrate differences between the outputs (Mull and Ruggiero, 2014). In addition, future shoreline changes have been modeled (Araujo et al., 2014; Young et al., 2014), aiding in highlighting areas and management techniques that should be further investigated.

In addition, LiDAR data can be combined with other auxiliary data. LiDAR data has been used in conjunction with multi-spectral images map coastal and estuarine habitat, and the incorporation of LiDAR data was demonstrated to enhance the accuracy of image classification, increasing the accuracy more than 10% in some habitat types (Chust et al., 2008). Similarly, hyperspectal imagery was used in conjunction with LiDAR data to refine salt marsh cover classes (Hladik et al., 2013). LiDAR has also been used to model habitat for threatened plant species in coastal areas, allowing for the identification of elevation as the most limiting factor to species distribution (Sellars and Jolls, 2007).

Although drastic changes to sea turtle nesting beaches have shown to be influential on nesting activities, sea turtles must also face changes on a lesser scale. Morphological alterations to the coastal landscape occur constantly, from daily wave and wind caused deposition and erosion to more infrequent, but larger, changes from storm and hurricane events. Nesting beaches from southern Florida are evaluated over a time span of seven years with three LiDAR datasets from 1999, 2004, and 2005 to evaluate how these nesting beaches change and determine what, if any, effects such changes have on nesting success.

2. Methods

Sea turtle nesting information was procured from the Florida Fish and Wildlife Conservation Commission (2008). Each surveyed nesting beach contains information about number of nests and false crawls (nesting efforts that do not result in a nest) per species, dates of nesting activity, and the number of days and length of beach surveyed. Beaches were included in this study if surveying was conducted between 1998 and 2005 with the surveyed area of a beach varying less than 0.25 km^2 between years, and if the number of surveying days conducted per week remained constant in order to highlight only those beaches with consistent surveying efforts. Beaches must also have been within the surveying area for the LiDAR data collection flights for the 1999, 2004, and 2005 datasets. A total of 18 beaches were included in this study (Fig. 1). Nesting success was used as a measurement to evaluate suitability of each beach, with the total number of nests per beach divided by the number of false and successful crawls (Brock et al., 2009) for the 1999, 2004, and 2005 nesting seasons.

LiDAR data from three dates were used: 1999 data from the Airborne Topographic Mapper (ATM) II (Krabill et al., 2000; Brock et al., 2002), 2004 from Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX) using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system (Wozencraft and Millar, 2005), which includes topographic and bathymetric data, and 2005 from JALBTCX, also using the CHARTS system (Wozencraft and Millar, 2005). The 1999 data had point spacing of 3.0 m, with a vertical accuracy of 15 cm and a +/− 0.8 m horizontal accuracy. The data was collected in November of 1999, with the flight lines covering from the low water line landward to the base of the sand dunes. The 2004 data had point spacing of 3.0 m density, with the horizontal and vertical accuracy of ~15 cm root mean square error. This post-Hurricane Ivan data was collected from November to December 2004. The 2005 data had point spacing of 1.3 m density, with the horizontal accuracy of the data better than +/− 3.0 m. The data was collected between December 2005 and February 2006. The JALBTCX LiDAR flights were typically conducted at low tide (Sylvester, 2011), and the timing of all LiDAR flights allowed for covering summer accretion before winter storm erosion. The LiDAR datasets were obtained from the NOAA Coastal Services Center's Digital Coast website in UTM Zone 17 projection with NAD83 horizontal and NAVD83 vertical datum, LAS 1.1 file format.

To reduce the effects from outliers during digital elevation model (DEM) creation, points with an elevation five or more standard deviations from the median value for each dataset were removed from the data clouds. To determine the pixel dimensions that best achieve a balance between small pixel sizes and a lack of empty cells, methodology previously used was applied (Yamamoto et al., 2012), with a ~800 m^2 area from Delray beach compared between the 1999, 2004, and 2005 datasets at varying pixel sizes. For each dataset, rasters with spatial resolutions varying from 2 to 5 m were created, with the percentage of empty cells calculated for the sample area from Delray Beach. By the 3 m pixel size, 1% or less of the pixels in the sample area contained no data for the 1999, 2004, and 2005 datasets (Fig. 2), and therefore a 3 m spatial resolution was used for all three datasets.

Shoreline demarcation using the LiDAR datasets was not ideal for this study. Because LiDAR collection is done near low tide, but not necessarily at absolute low tide, it is possible that observed changes in beach areas above water across years will differ due to tidal changes and not to changes in beach areas over time. Therefore, to ensure consistent area comparisons between years, the St Johns River Water Management District (2011) dataset was used to identify the beach area. This dataset is derived from color infrared (CIR) digital orthophoto quarter quadrangles (DOQQs) from the United States Geological Survey (USGS) with spatial resolutions of 1:12,000. These orthophotos were used to create land use and land cover designations for 1999 for Florida as polygons, which were used as the demarcation for beach areas by Long et al. (2011) to compare beaches in Florida using LiDAR data from different dates. Beach orientation was obtained from these polygons.

The elevation surfaces derived from the LiDAR data were used to obtain slope, aspect, rugosity, and Terrain Positional Index (TPI) for the delineated beach areas. All buildings and other non-beach entities were removed from the surfaces prior to analysis. Rugosity, defined as the ratio of the surface area to the planar area (Jenness, 2011), and TPI, which illustrates a pixel's position in relation to other pixels on a surface, are often used in topographic and bathymetric studies to characterize the land and sea surfaces (e.g. Iampietro and Kvitek, 2002; Weiss, 2001; Lundblad et al., 2006; Wedding et al., 2008). Rugosity measurements were achieved using the DEM Surface Tools for ArcGIS 9.x (Jenness, 2011), and TPI measurements with using the CorridorDesigner extension