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High Resolution Dune Complex Mapping for the Monitoring of Coastal Landform Change, First Landing State Park, Virginia

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ABSTRACT

First Landing State Park is located on the southern shore of the mouth of the Chesapeake Bay. The park contains a prograding shoreline and dune complex that has been steadily growing northward. Accurate three dimensional mapping of the resident coastal dune features is challenging due to the dynamic nature of the dunescape. Precise mapping within First Landing was accomplished through careful planning, employ of advanced Global Positioning System (GPS) technology, and intensive data analysis. Mapping ensued during a period of optimal satellite signal availability and strength. Data points were collected at manual intervals with a *Leica* GS50+ GPS receiver, utilizing real-time kinematic (RTK) corrections from ground control stations. Vertical data accuracies of less than 5cm were achieved. Horizontal accuracies were near 1cm. The resultant data was interpolated to create realistic contour maps, triangulated irregular networks (TINS), and raster elevation models of the study area. The methods employed may be replicated at standard time intervals for the purpose of establishing a database to maintain an inventory of dune features within First Landing. Temporal changes in this inventory may be monitored to illustrate rates of change and illuminate conditions that may require management intervention.

INTRODUCTION

First Landing State Park is located on the southern shore of the mouth of the Chesapeake Bay. It was bought by the Commonwealth of Virginia in 1933, dedicated to the citizens of the Commonwealth in 1936, and added to the National Register of Natural Landmarks in 1975. It is the most northern point on the United States East Coast where temperate and subtropical plants grow together. The park consists of cabin rentals, campgrounds, an environmental educational center, nature, hiking and biking trails. This park is one of Virginia's most popular and attracts tens of thousands of tourists per year.

Since the end of the last major glacial event, relative sea level has been rising. The term "relative" is used to indicate sea level when compared to land surface elevation. Land subsidence can result in increases in relative sea level that are much higher than the rate at which the sea itself is rising (Poag, 1999). The increase in relative sea level has inundated and eroded a significant portion of the Virginia coast. However, eroded sediments do not vanish. They are transported and deposited elsewhere. The Cape Henry coast is essentially a left-handed spit built up from sediment eroded from the beaches further south by a process called longshore drift. This current of moving sand runs into the Chesapeake Bay and is disrupted by east-west trending tidal currents. These tidal currents then redistribute the sand onto the shoreline of the Chesapeake Bay and into shoals in the Bay mouth (Figure 1). This influx of sand builds up, resulting in the northward advance of the shoreline. Over long periods of time, this erosion, transportation and redeposition of sand along Virginia's southeast coast has built up the large prograding shoreline/dune complex that is Cape Henry (Figure 2). The dunes in the Fort Story area, north of the visible dune crests, are not as visible as construction in/around the base has disrupted the natural visible pattern.

Precision mapping of areas of the shoreline and dune complex subject to these erosional and depositional forces can serve as an essential tool for coastal resource managers. This area mapped in this study was roughly rectangular portion of the backshore area on First Landing State Park between the camp store beach access walkway and next adjacent wooden walkway to the east. The northern limit of the mapped area was the shoreline at mean high water (MHW). The edge of the maritime pioneer forest served as the southern boundary. The mapped area has a series of three dune crests separated by shallow swales that deepen as one moves inland. The dunes closest to the beach, the foredunes, are sparsely vegetated with beach grass and secondary vegetation that traps "wind blown sands and cause(s) the foredune to grow vertically. . ."(Hardaway et al., 2001). In a report commissioned by the U.S. Army Corp of Engineers, W.W. Woodhouse (1978) states that, "New barrier dunes develop in this zone and the pioneer plants are usually used to build new dunes or to stabilize bare zones". The area immediately behind the foredune, the "scrub or Intermediate Zone" (Woodhouse, 1978), consists of two secondary dune crests separated by swales. Here, the vegetation is less sparse, trapping wind blown sand that acts to stabilize the area (Hardaway et al., 2001). The southern edge of the third dune begins the tree line, defined by Woodhouse (1978) as the "Forest Zone", and is populated by short, windblown trees and scrub brush. The campsites are located just beyond and, in rare cases, on top of the third dune line. Numerous trails were observed winding through the dunes to the campground areas. These trails appear to have been made by campers desiring an easy path to the beach. The creation of the trails has depleted the vegetation along their route and has destabilized the dunes and swales, creating slight trenches. While no wildlife was observed, evidence of fauna consisting of herbivore scat and crab burrows were seen scattered throughout the dunes.

MATERIALS AND METHODS

All significant aspects of a precision mapping project must be articulated before venturing into the field so that they may be performed effectively. A preliminary field survey of First Landing State Park was conducted for the purpose of delineating study area limits, data acquisition times, and mapping techniques. It was determined that

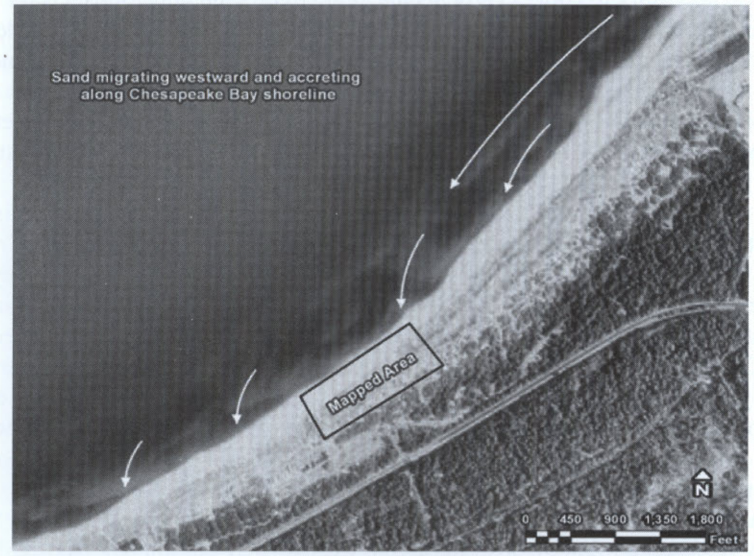

FIGURE 1. Longshore drift and accretion at First Landing State Park.

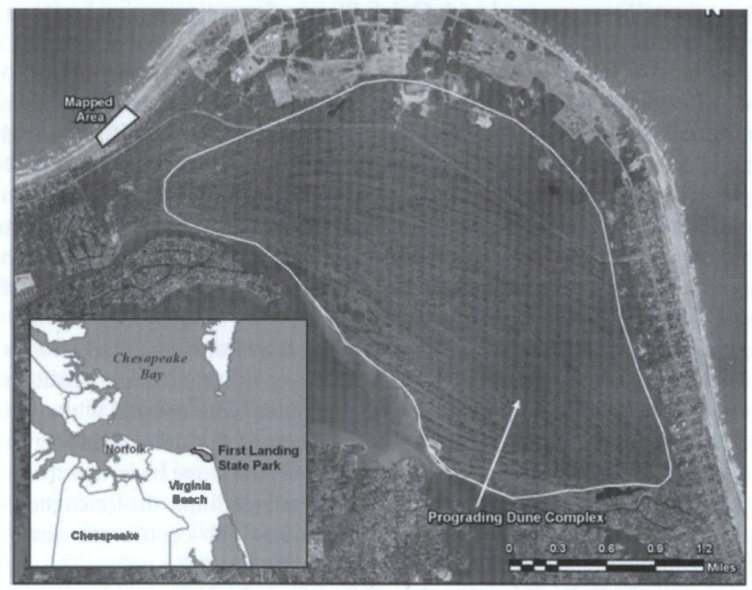

FIGURE 2. Cape Henry dune complex and First Landing State Park mapping site. Aerial Imagery © 2002 Commonwealth of Virginia.

it would be necessary to collect vertical data along three sand dune transects for use in subsequent interpolation of contour lines. In complement to these dune profiles, the capture of shoreline, berm, toeslope, vegetation line, swale, dune crest line, and foot path features was deemed critical to the creation of detailed contour and terrain maps. No significant obstructions were observed that would prevent data collection between the two beach access boardwalks lying to the east-northeast of the park's administrative center.

Two Global Positioning System (GPS) receivers were used for data acquisition. Data that did not mandate accurate vertical measurement was captured with a Trimble GeoXT GPS unit. The GeoXT receiver has sub-meter horizontal accuracy and integrates WAAS and EVEREST multi-path rejection technology for the elimination of satellite signal noise and interference. All critical elevation data were recorded with a Leica GS50+ GPS receiver. The GS50+ employs the use of a Real-Time Kinematics (RTK) system to obtain in vertical accuracies of ±5 centimeters. In the kinematic mode, corrections to the signals of the moving receiver are calculated in real-time from another, simultaneously operating base receiver fixed in a nearby position (Nickitopoulou et al., 2006).

Regardless of the RTK capabilities of the receiver, the accuracy of any GPS data is greatly dependant upon the availability and strength of satellite signals. Software programs are used to predict satellite availability, determine the best observation periods for a collection session, and visualize satellite availability. The Quick Plan mission planning software (Trimble) was used for this study. Almanac files, generated from orbiting satellites, are used with Quick Plan to determine optimal criteria for the geographic position of the study site, 36 55.16' N, 76 03.2' W. An almanac is a set of data that is used to predict satellite orbits over a moderately long period of time. Positional dilution of precision (PDOP) of the satellite data were derived from the combination of satellite signal strength data and available almanac files. Field forays were scheduled for periods of optimally high satellite availability and low PDOP.

Data collection commenced during calm weather conditions to minimize the potential effect of wave action on shoreline observations. The shoreline feature was recorded as a line type vector data feature and was taken near mid-tide in order to simulate mean sea level. Lunar cycles were determined to have a negligible effect on the mapping output and were disregarded.

Nine predetermined "control points" within the dune field were marked with survey flags and would be used to identify the locations of three dune profile transect measurements. Several feature classes and attributes were created in the Leica data logger in order to increase the speed and efficiency of the dune mapping process. These features included: swale lines, dune crest lines, toe slope base, and transect/spot elevations nodes. To ensure the most accurate vertical readings, the Leica receiver was deployed on a 7' pole attachment. This ensures sub-centimeter accuracy by automatically adjusting all readings by the exact height of the pole. This compares favorably to use of a backpack-mounted receiver for which the height of the receiver is not a constant.

The receiver was calibrated for the manually recording of horizontal and vertical (x, y, z) data nodes. Manual data entry is more time consuming than automated data logging, but allows the researcher to exercise precise control over each measurement. Nodes were recorded approximately every 20 paces in dune crest and swale lines. User

FIGURE 3. Operation of Leica GS50+ RTK GPS receiver by Jim Collins in mapping the dune field.

discretion was applied in determining if the distance was to be increased (over long evenly sloped sections) or decreased (upon major changes in slope). Vertical measurement errors caused by the depth of the sandy surface were avoided by placing the base of the Leica receiver pole gently and precisely atop the sand for each measurement (Figure 3). The path of each crest and swale line was not geometrically predetermined. The shifting nature of the dune pattern required human discretion to determine the continuity of these features. These crest and swale lines were delineated by consensus. The dune transect nodes, however, were determined in a strictly purposive manner. These profiles were recorded by a manual recording of GPS points at every major change in slope along the pre-marked transect. Node recording for each transect began at the toe of the first barrier dune and continued until the campground canopy was reached. This data was recorded entirely as a collection of nodes rather than a line feature primarily because there is no true linear topographic feature that cuts through the study area in this manner.

At the conclusion of the collection period data were immediately downloaded and reviewed on a field located laptop. The visual display of the data readings confirmed the recordings to be congruent with the mapping objective. Data from the Leica receiver was subsequently exported into ASCII text and then converted to shapefiles (ESRI). The ASCII text files were generated to ensure the display of the vertical value for each node along the swale and dune crest lines. These data were imported into Microsoft Excel as comma delimited text files in order to maintain X, Y, and Z data

columns. Each column was formatted to include numbers up to 2 decimal places. The data were then exported as a .dbf (IV) file type and then used to generate data point features in the ArcGIS 9 (ESRI) software.

All data were post-processed against the CORS (continuously operating reference station), Loyola Enterprises Chesapeake, VA base station and exported as an ESRI shapefiles. This post-processing applied a differential correction that further improved the accuracy of each reading.

These post-processed node data were interpolated to a raster grid within the ArcGIS Spatial Analyst using an ordinary kriging algorithm with a spherical variogram model. Kriging is a method for linear optimum unbiased interpolation with a minimum mean interpolation error (Theodossiou and Latinopoulos, 2006). The primary concern of the use of any interpolation technique is with the imprecision of the original data. This particular concern was eliminated by the use of precision RTK adjusted GPS data. Grid parameters were set to a fixed search radius of 150 feet, minimum acceptable value of 0 and a grid cell size of 25 feet. These parameters were chosen to allow statistical infilling of the entire project area without too much smoothing of the raw data or too much grid extrapolation beyond the control points. Surface Analysis was utilized to construct the contours from the grid. Contouring every foot with base contour set to 0 and no z factor scaling was accomplished and overlaid on the grid surface for a final contour map of the study area (Figure 4).

The 3D Analyst ArcGIS extension and ArcScene were used to create a visualization of an approximate surface of the study area. The elevation values of the interpolated raster were exaggerated to provide visible contrast within a simple three-dimensional model of the ridges and swales of the dune field (Figure 5). In addition to the production of detailed visual representations, these data allowed for the calculation of the area and volume of the study area. Approximately 40360 square meters of dune field were found to represent an above-MSL volume of 135000 cubic meters of sand. This volumetric calculation is a critical and easily replicable component of the monitoring of temporal changes in an observed dune field.

DISCUSSION

The development of increasingly accurate GPS technology allows for precision mapping of coastal topography. Accurate, localized topographic maps may be produced and utilized to support the analysis of change within the coastal zone. However, advanced technology must be combined with comprehensive human knowledge of geospatial techniques in order to be completely useful. Schubel (1981) asserts that, while changes in the coastal topography of the Chesapeake Bay typically occur on geological time scales, poor planning and conservation could reduce the functional lifespan of the Bay by half. This concept can be applied to terrestrial landforms and their accompanying bays throughout the mid-Atlantic and reinforces the need for mapping and cataloging of the coastal zone.

The data mapped in our study confirm the existence of dune patterns similar to those identified in another recent analysis performed in coastal Georgia and North Carolina. This study indicates that, "Elevational contrasts are maintained by positive relief generated by dune-building taxa and stabilization of intervening low swales by burial-intolerant woody shrubs and grass species" (Stallins and Parker, 2003). When

FIGURE 4. Contour and feature map. Feature widths are enlarged to enhance visibility. Aerial Imagery © 2002 Commonwealth of Virginia.

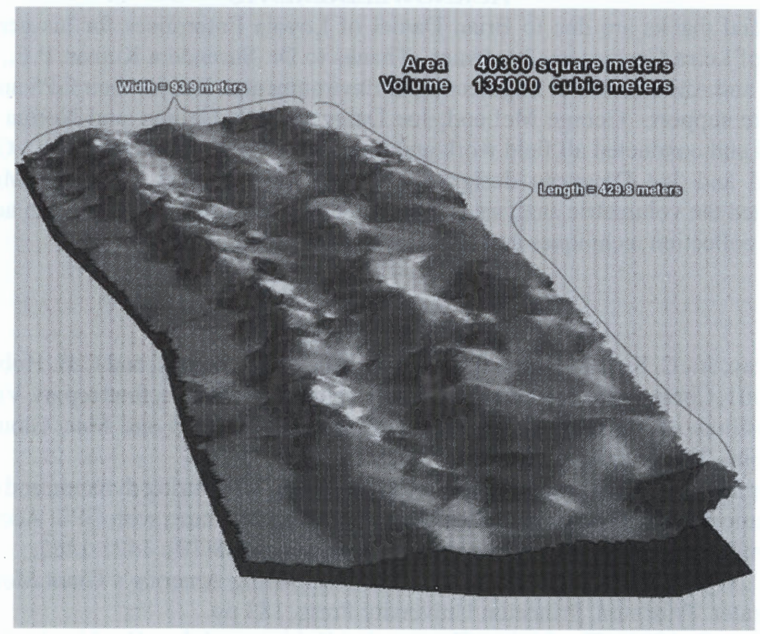

FIGURE 5. Preliminary 3-D elevation model of mapped dune field.

used properly, data such as those obtained through our study may be used to "extract" much broader conclusions about environmental change over time.

The maps resulting from this study cover a small portion of a much larger geographical area and body of knowledge. At the First Landing State Park mapping site, both visual and GIS inspections reveal a persistent pattern of shoreline advance and new dune ridge formation. Three separate dune ridges and accompanying swales were mapped between the current mid-tide shoreline and the vegetation line. The evidence suggests that the entire complex is advancing northward. The current shoreline has advanced noticeably northward from its position at the time of a 1994 aerial photograph of the study site.

The techniques used to produce the resultant digital topographic data were designed to be easily replicated. Through replication of these methods at standardized time intervals it will be possible to quantify and catalog changes in the positions of the shoreline, foredunes, dune ridges, and pioneer forest. Comparison in the position of the shoreline over time coupled with the dune elevation changes would afford an estimate of the rate at which sedimentation is taking place. By way of example, if the elevation of the newest dune has increased 6 inches, on average, over a decade, this might suggest that in 400 years this dune will have an elevation of 20 feet, while the shoreline will have advanced some 70 feet northward. It is also possible to use this estimated sedimentation/dune growth rate to construct regressive and/or predictive models of the topography. These models could provide a visualization of what the coastline may look like in the future or what it may have looked like in the past.

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