Defining and Mapping Foredunes, the Line of Vegetation, and Shorelines along the Texas Gulf Coast

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Final Report

Prepared for

Texas General Land Office
Contract Number: 07-005-22
Project Title: "Status and Trends of Dune Volume, Morphology, and Vegetative Cover along the Texas Gulf Shoreline"

A Report of the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA06NOS4190219

December 2009

Introduction

It is well know that wide, high, and well-vegetated foredunes are aesthetically pleasing, an important habitat within the beach/dune system, protect landward areas from storm damage, and are a source of sand to speed beach recovery after a storm. Gibeaut et al. (2002) showed that along the upper Texas coast washover and damage to beach-front construction from tropical storms with surges up to 1.5-m high does not occur where the foredunes are at least 3-m high or 30 m wide. They also showed, however, that much of the developed areas along Galveston Island and Bolivar Peninsula did not have this level of protection and suffered episodic damage from Tropical Storms Josephine and Frances in 1996 and 1998, respectively. Protection of natural foredunes and their enhancement is an excellent way to decrease the susceptibility of the shoreline to storm damage while improving the beach/dune environment. This project provided data and information to better understand the protective role of foredunes and to help protect them from destructive practices. The focus of this report is the development of the criteria used for defining the landward and seaward boundaries of the foredune, defining the landward boundary of the public beach easement (line of vegetation), and defining the shoreline for shoreline change analysis. We make recommendations on how to map these lines and on strategies for developing construction setback distances.

Foredunes and the Open Beaches Act

In Texas, the Open Beaches Act (OBA) defines the landward boundary of the public beach easement as the "line of vegetation." The act further defines the line of vegetation as "the extreme seaward boundary of *natural* vegetation which spreads continuously inland." No obstructions to the public's use of the beach may exist seaward of this line. The public beach easement is a "rolling" easement. For example, if the beach erodes and the line of vegetation retreats to a position landward of houses, then the owners of those houses could be in violation of the OBA. In areas undergoing vegetation line retreat, the rolling easement does not preserve the foredune because structures come to occupy the space needed for foredune formation (Fig. 1). Although the OBA is not a law designed to conserve or promote development of protective foredunes, determining construction setback distances based on the natural line of vegetation and

expected natural widths of foredune zones could help serve that purpose. Several difficulties, however, regarding the demarcation of the line of vegetation exist along the Texas Gulf coast.

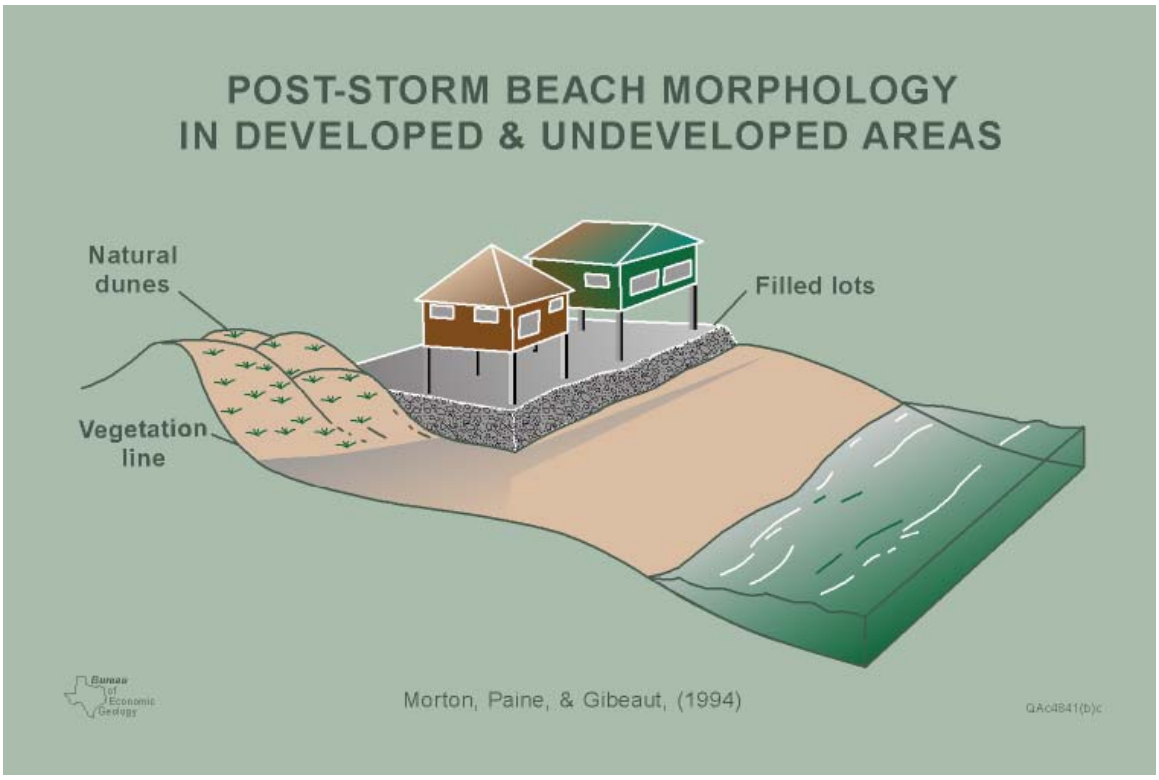

Figure 1.- As the beach retreats, structures prevent foredune formation, which increases the rate of retreat and causes hazardous conditions (from Morton, Paine, and Gibeaut; 1994).

The density of naturally occurring vegetation varies along the Texas coast in time and space. The upper coast receives enough rainfall to allow dense dune and back barrier vegetation to grow. Along the arid lower coast, however, areas with fully developed vegetation may only cover the sand by 50%. A storm may cause the line of vegetation to retreat to a position landward of structures in one day, effectively placing those structures on the public beach easement. Seaward advance of the vegetation line during natural recovery of the post-storm beach occurs at different rates alongshore and may not occur at all in some places. Furthermore, where recovery is occurring, the density of vegetation may be considered for a time to be something less then “spreading continuously.”

Furthermore, according to the OBA, the landward boundary of the public beach easement is the *natural* line of vegetation and cannot be advanced seaward through artificial means. In many places, artificial manipulation of the line occurs through beach and dune restoration, beach

scraping, beach driving, turf placement, and geotextile tube projects. Even though these actions may be allowed, they can narrow the public beach and maps should represent where the *natural* line of vegetation *could be* even in the presence of human manipulation. This is not only important for enforcing the OBA, but also for designing dune restoration projects and limiting construction in areas of potential foredune formation.

There are places where the line of vegetation is not continuous alongshore such as dune blowout and washover areas. In areas like these the OBA states “The "line of vegetation” for the unmarked area shall be the line of constant elevation connecting the two clearly marked lines of vegetation on each side.” Detailed topographic data, therefore, are required to map completely the line of vegetation. Topography is also needed to help discriminate among artificial and natural vegetation lines.

Determining the Shoreline Feature, Seaward Limit of Potential Foredune Formation, and Landward Foredune Boundary

Consistently and rigorously mapping the natural line of vegetation is problematic with respect to using it for a legal boundary. Furthermore, the natural line of vegetation at a given time does not necessarily reflect where the seaward limit of protective foredunes or zone of potential *vegetated* foredune development occurs. For these reasons we sought to determine a more useful criterion for defining the landward boundary of the rolling easement while at the same time providing a meaningful line from which to measure construction setback distances or to use for designing dune restoration projects. Morton, Paine, and Gibeaut (1994) described phases of beach and dune recovery along Galveston Island following Hurricane Alicia in 1983. Foredunes did not begin to reform until the back beach aggraded to an elevation high enough for sand to dry out, making it available for wind transport to the landward zone of vegetation and foredune formation. Elevation is a key parameter, therefore, for determining the seaward limit of potential dune formation.

Beach Profile Measurements

Since 1994, the Bureau of Economic Geology (BEG), and more recently the Harte Research Institute (HRI), have ground surveyed topographic transects (beach profiles) at more

than 68 locations along the Gulf of Mexico shoreline suitable for determining the natural elevation of the line of vegetation (Fig. 2). These locations span the Texas shoreline and those in more accessible areas such as Bolivar Peninsula, Galveston Island, Follets Island Matagorda Peninsula, Mustang Island, North Padre Island, and South Padre Island have been measured more than once and up to 40 times from 1994 to 2009. During this study, some of the beach profiles were newly established, reestablished, and re-measured.

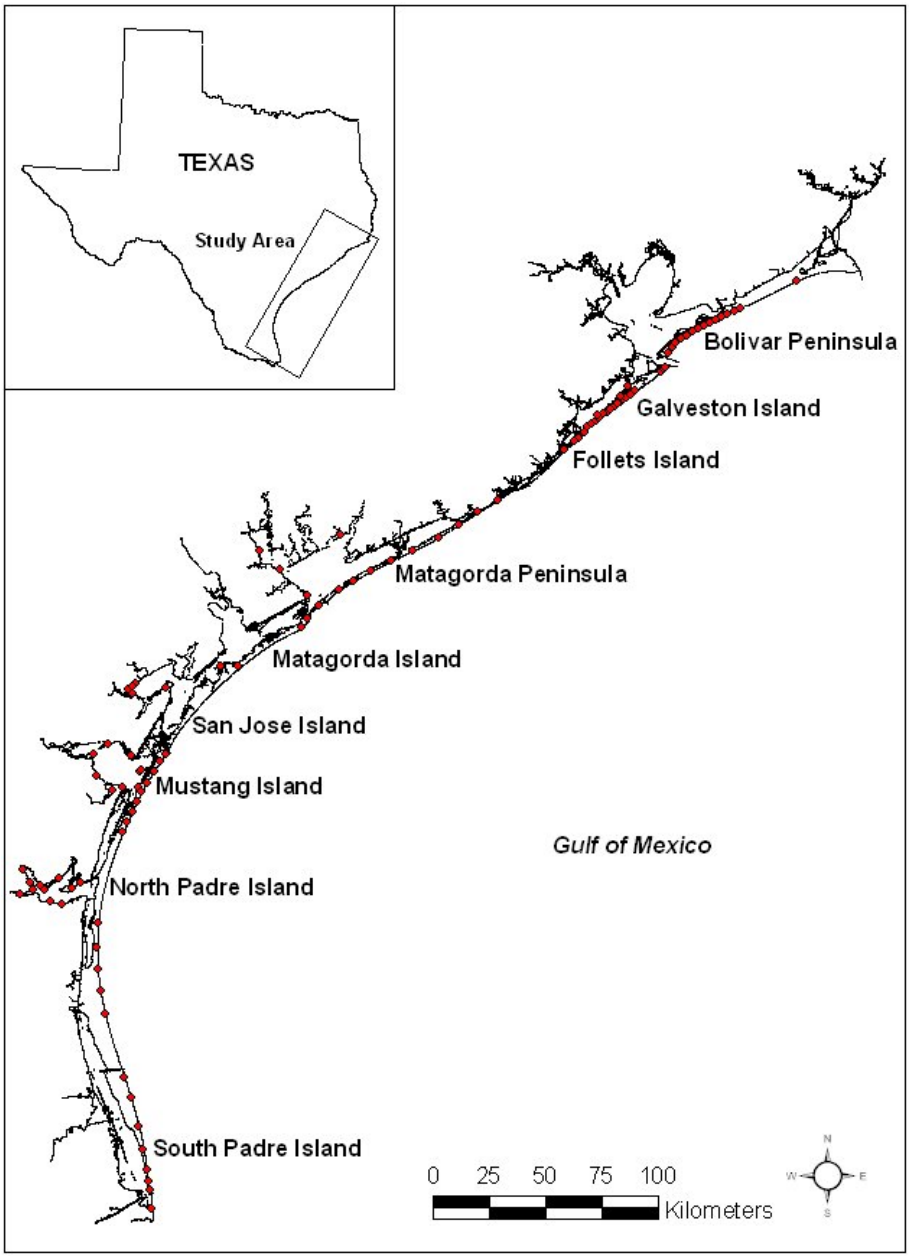

Figure 2.- Beach profile locations (red dots) along the Texas coast. Gulf locations were used to determine line of vegetation elevation statistics.

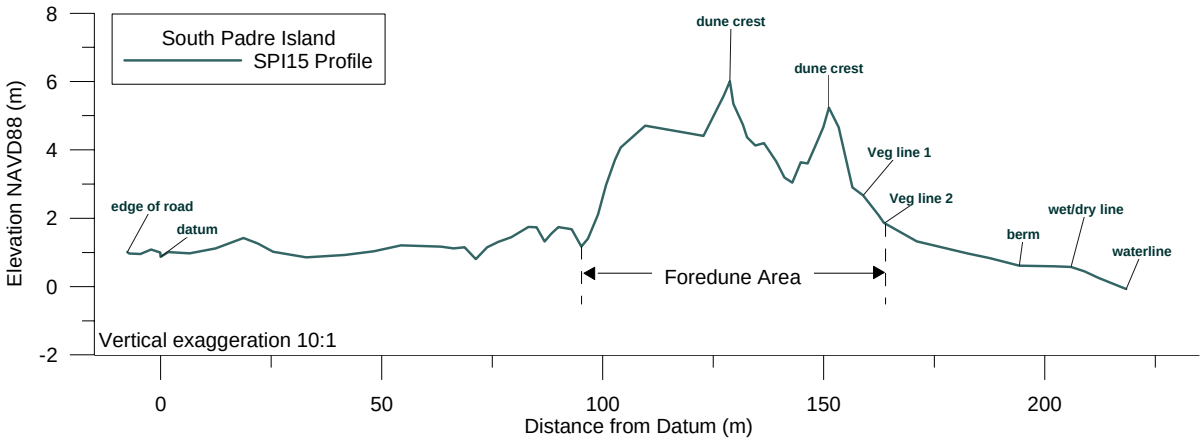

Figure 3.- Example beach profile measured on August 24, 2009 on South Padre Island.

The beach profiles are oriented perpendicular to the shoreline and extend from landward of the foredunes to the water's edge, or in some cases, wading depth (Fig. 3). Observations and notes regarding geomorphic features and the vegetation line location are made along the profiles. Often two or more vegetation lines are noted depending on if there is a distinct change in vegetation cover along the profile. The first, or most landward, vegetation line marks the seaward limit of relatively continuous vegetation cover while the second vegetation line marks the seaward edge of sparsely vegetated coppice mounds or pioneering vegetation extending onto the back beach.

At each profile location an existing stable structure, such as a fire hydrant or corner of a foundation, or a temporary marker that we bury serves as a reference point for repeating surveys. The reference marker of each profile was surveyed using precise differential GPS techniques. The reference GPS network used is the Continuously Operating Reference Stations (CORS) operated by the National Geodetic Survey. Geodetic-quality GPS receivers acquired data at each profile site for 30 minutes or longer depending on the distance from the nearest GPS reference station and the satellite constellation. GPS data were processed using phase differencing techniques to provide positions of the reference markers. Positions are computed in the UTM coordinate system using the NAD83 datum. Vertical measurements are expressed as heights above the reference ellipsoid (HAE). Using the Geoid99 model, HAE heights were converted to orthometric heights relative to NAVD88. Local mean sea-level offsets from NAVD88 are calculated at two open-ocean tide gages: a gauge on Pleasure Pier on Galveston Island and a

gauge on Bob Hall Pier on Mustang Island (Fig. 2). These vertical tidal datum offsets are determined by the Blucher Institute of Texas A&M University-Corpus Christi.

Beach profiles were measured using an Electronic Total Station and a reflecting prism or an Emery rod technique involving a hand level and graduated poles. We estimate that the elevations of the vegetation lines and other points along the beach profiles are accurate to within plus or minus 0.1 m and for select profiles within 0.02 m. This estimate includes the uncertainty of the reference marker elevations and the error in determining elevation differences from the reference marker along the profile. The beach profile data are housed in a database maintained by the BEG and HRI.

Elevation of the Line of Vegetation

Of the locations with beach profile measurements, 68 were determined to be suitable for representing the natural elevations of their vegetation lines based on observations in the field. Locations with structures, such as geo-textile tubes or seawalls, directly impacting depositional processes on the back beach are not considered suitable. A total of 399 measurements taken at the 68 locations were determined to be suitable for the landward vegetation line (Fig. 4). Measurements following storms when a scarp was left on the seaward face of the foredune were not used. Of the 399 measurements, 230 are on Galveston Island or Bolivar Peninsula at 34 locations. Along the middle and lower coast, a total of 170 measurements at 34 locations were included in the analysis.

Table one shows the results of the analysis. As expected, the mean elevation of the landward line is higher than the seaward line, and the distribution of the elevations is approximately normal with a skewness toward higher elevations. Subtracting one standard deviation from the mean, therefore, yields an elevation where at least 84% of the lines of vegetation are statistically expected to be at the same height or higher than 1.27 m NAVD88, assuming the frequency distribution of the population of vegetation heights is normal.

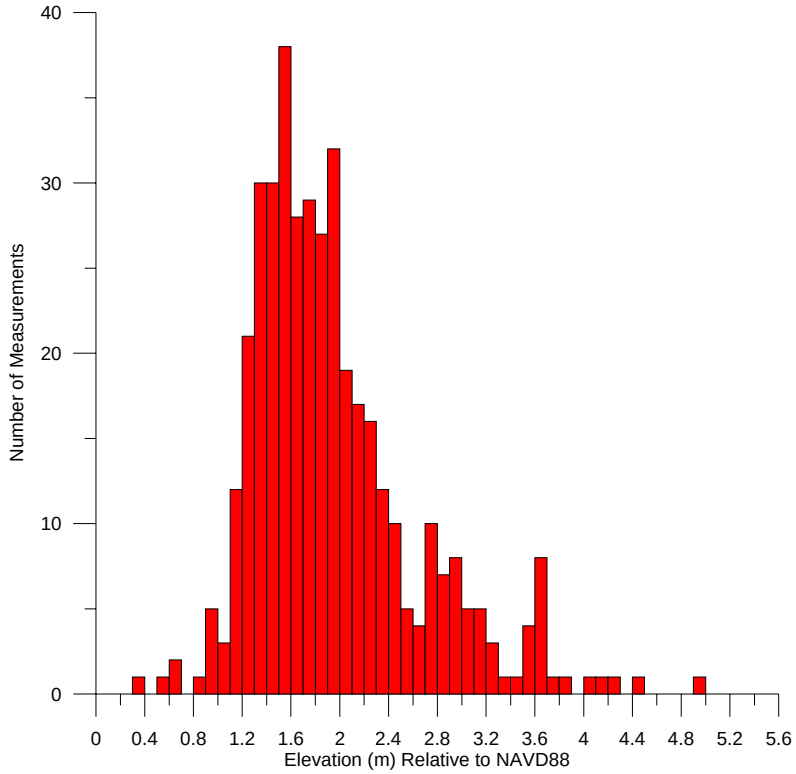

Figure 4.- Histogram of the elevations of the most landward vegetation lines from the Gulf coast.

Table 1: Elevation (NAVD88) values in meters of lines of vegetation

	Landward Line, n= 399	Seaward Line, n= 82
Mean	1.95	1.665
Standard Deviation	0.68	0.39
Mean minus Std. Dev.	1.27	1.27
Approximate vertical difference between NAVD88 and mean-sea level	-0.065	-0.065

The elevation for determining the line of vegetation should be relative to a tidal datum because water level is a primary physical control on the elevation of the vegetation line. As sea level changes, therefore, the line of vegetation will move with it, and if the line is defined relative to mean sea level, the value used for elevation above sea level would not need to change. NAVD88, on the other hand, is a fixed datum not coupled to future changes in sea level.

NAVD88 varies from mean-sea level along the open Texas coast. There are two open-coast tide gauges at which the vertical offsets of NAVD88 and local mean-sea level have been determined, and will continue to be determined as sea level changes, by the Blucher Institute at

Texas A&M University-Corpus Christi. At the Pleasure Pier tide gauge on Galveston Island, mean-sea level is 0.15 m higher than NAVD88, and at Bob Hall Pier on North Padre Island, mean-sea level is 0.02 m below NAVD88. The mid point between these two measurements is 0.065 m. To arrive at a compromise elevation of the seaward boundary of the potential line of vegetated foredunes, we subtract 0.065 m from 1.27 m to arrive at 1.20 m above mean-sea level after rounding. More open-coast tide gauges are sorely needed to better define the vertical offsets from NAVD88 along the Texas coast.

A question remains if the elevation of the vegetation line varies along the Texas coast and whether or not different elevations should be defined for representing the line of vegetation. There is an indication that the middle coast (North Padre, Mustang, and Matagorda Islands, Fig. 2) tends to have higher vegetation line elevations than the upper or lower coasts. Abundant sand supply in the middle coast could explain this difference. However, the temporal variation of the vegetation line elevations at given locations is greater than the alongshore variation. Given the state of the data at this time, therefore, we think all suitable measurements should be used to arrive at a single value for Texas.

Landward Boundary of the Foredune

Mapping the landward boundary of the foredune is important to determine the space required for foredune formation where a foredune has been destroyed or preempted by structures. This boundary could be used to design setback distances and foredune restoration projects. It is also needed, in conjunction with the seaward boundary, to define the area for volumetric and geomorphic analysis of the foredune. Defining the landward boundary of the foredune using an automated process, such as contouring, has yet to be proven effective.

The point at which the wind deposits, and in some cases washover deposits, of the foredunes end and the back barrier flat, beach ridge, back barrier dunes or some other geo-environment begins is a function of several observable conditions that are difficult to consistently quantify. Some areas are more complicated than others, and this study worked on criteria for mapping this boundary by looking at the relatively simple foredune complex on the upper Texas coast and the complicated situation on Mustang Island in the coastal bend. On Mustang Island, a major difficulty is determining where the foredune complex ends and back barrier dunes begin. Following is our current criteria used in a qualitative sense: (1) a change in

slope from steep on the foredune to gentle on the back barrier; (2) elevation generally 1.2 m above mean-sea level; (3) provides storm-surge protection; (4) morphology is elongate parallel to the shoreline; (5) Proximity to the shoreline and other forms classified as foredunes; (6) Connection to other forms classified as foredunes; and (7) Density of clusters of dune forms.

We continue to explore quantitative and semi-quantitative measures of defining the foredune. For this project, however, mapping was accomplished through on-screen manual digitization of images that combined color infrared photography and lidar-derived Digital Elevation Models (DEM) (Fig. 5). Hill shading, texturing, and 3-d views aided in the interpretation of the line. Field checks and beach profiles were also consulted.

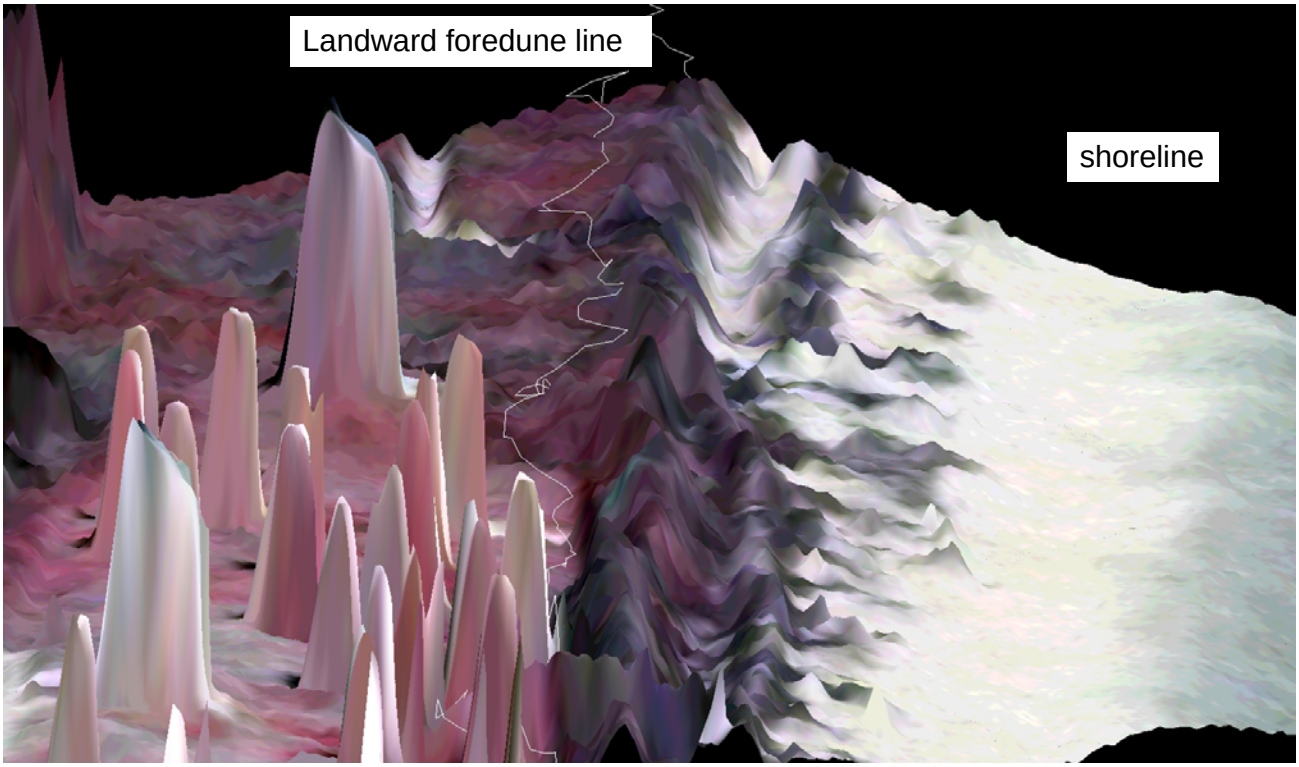

Figure 5.- Color Infrared photography draped on a lidar-derived Digital Elevation Model (DEM). Imagery like this is used to virtually walk the shoreline and map the landward extent of the foredunes.

Shoreline Feature

Most of the shorelines in our historical shoreline database were mapped using vertical aerial photographs. The shoreline was interpreted and drawn or digitized on the photograph and transferred to a base map for comparison with earlier shorelines. Typically, the boundary between wet and dry sand on the beach, which is displayed as a tonal contrast on the

photographs, is used as the shoreline. This boundary, however, is affected by recent water level and wave activity and may not be a reliable indicator of shoreline position. Error is also introduced to the shoreline position when the photograph is georeferenced. Because lidar surveys are GPS based, there is no need for transferring data or rectifying photographs. Furthermore, a contour line can be used as the shoreline, eliminating the ambiguity present in the wet sand/dry sand boundary.

Gibeaut et al. (2003) showed that the wet/dry boundary on the beach usually corresponds to a point just below and seaward of the major active berm on the beach and that this geomorphic point forms the best feature for defining the shoreline for long-term shoreline change analysis (see Fig. 3 for example). Furthermore, the current study has determined through repeated beach profile and lidar surveys that the wet/dry line typically occurs at 0.6 m above local mean sea level. Therefore, the shoreline indicator derived from the lidar data for this study is the seaward most point on the beach that is 0.6 m above local mean sea level. Using a lidar-derived contour line as the shoreline for shoreline change analysis is more rigorous than extracting wet/dry lines from aerial photography. Furthermore, using an elevation corresponding to the typical wet/dry line has several advantages over using a lower tidal datum such as means-sea level or mean-high tide: (1) it is comparable with past wet/dry line shorelines; (2) it is more often above water and able to be mapped by lidar than lower elevations; and (3) it is above high-frequency changes occurring on the lower beachface such as swash bar movements or cusp formation that do not indicate long-term shoreline change.

Mapping the Lines

A combination of vertical aerial photography, high-quality topographic lidar, and beach profiles are needed to map the foredune and shoreline. Georeferenced, color infrared photography with 0.5 m resolution is required for assessing vegetation and foredune characteristics. The fundamental data needed, however, are highly accurate and detailed topographic models that can only be acquired using airborne lidar.

Airborne Topographic Lidar Surveys

In 1997, the BEG began acquiring high-accuracy lidar topographic data of the beaches and dunes along the Texas Gulf coast (Gutierrez et al. 2001). More recently, these data have

been acquired by a team from the BEG, Center for Space Research at The University of Texas at Austin (CSR), the Blucher Institute at Texas A&M University-Corpus Christi, and HRI. These data provide a continuous topographic model of the beach and foredune system extending 300 to 800 m landward of the shoreline.

Airborne lidar mapping requires the integration of three basic measurement sources: (1) laser ranges and associated scan angle information; (2) aircraft attitude information from an inertial measurement unit (IMU); and (3) absolute aircraft trajectory derived from a differential, geodetic global positioning system (GPS) network (Wehr and Lohr, 1999). The laser used to acquire the data analyzed in this study is a pulsing, solid-state, infrared laser with a wavelength of 1064 nm. Lasers of this wavelength do not penetrate water and are blocked by clouds. The IMU (set of three orthogonal accelerometers and gyroscopes) records the aircraft attitude 50 times per second (50 Hz); a GPS receiver provides aircraft position data once per second relative to simultaneous operating ground GPS reference stations. An oscillating scanner mirror in the instrument sensor head sends laser pulses across the ground in a zigzag pattern perpendicular to the direction of flight to illuminate a swath underneath the aircraft.

For Texas Gulf shoreline surveys, we install an Optech ALTM 1225 lidar instrument in a Cessna 206 aircraft operated by the Texas Department of Transportation. A video camera with the same look direction and field of view of the lidar scan is used to fly along the shoreline. To acquire the highest quality data, we fly low (800 m or lower), slow (50 m/s), only during times of optimum GPS satellite constellations, and generally stay within 30 km of a ground reference station. We also fly over a ground calibration target during each flight, and we fly two to four passes along the shoreline to acquire several laser points per square meter. Processing of the raw survey data to compute x,y,z points is conducted using a hands-on process to assure data quality. The x,y,z points are gridded into a DEM using an inverse distance weighted algorithm. Details of the parameters for specific surveys and processing routines can be found in the metadata. Accuracy typically obtained on non-vegetated surfaces is 0.1 m Root Mean Square Error.

Recommendations

1. Because of the difficulty in rigorously mapping the landward boundary of the public beach easement as the line of vegetation, we recommend that the seaward most contour line with an elevation of 1.20 m above mean-sea level (msl) be used as the boundary.

This line will either be within the vegetation or coincide with the vegetation line. Where it is seaward of the vegetation, it indicates the potential position to where vegetation and the foredune may advance. Continued measurements may allow refinement of this elevation for separate coastal compartments such as the upper, middle, and lower coasts.

2. Quantitative and consistent criteria for defining the landward boundary of the foredune are not currently available. Therefore, this boundary should be defined using qualitatively consistent criteria as described in this report.
3. The seaward most contour line with an elevation of 0.6 m above msl should be used to define the shoreline for shoreline change analysis and for measuring the width of available beach for public use. This line is comparable to the wet/dry line mapped on photography as the shoreline.
4. The shore-normal width of the typical foredune for a particular area should be used in conjunction with the location of the 1.20 msl line to determine the setback distance after destruction of the foredune by a storm or ongoing shoreline retreat and encroachment of structures. This study has determined that along the upper coast, this width is 60 m but it varies elsewhere on the Texas coast. Additional setback distance should be added based on the long-term shoreline change rate of an area. Continuing work is defining the required width for foredune development along other parts of the Texas coast.
5. High-accuracy, topographic lidar data are essential to map the foredune and shoreline, and these surveys should be conducted annually along the Texas Gulf coast. Color infrared, vertical aerial photography also aids the delineation of the foredune and should be acquired within 2 weeks of the lidar data.

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