TOPOGRAPHIC VARIATION OF BARRIER ISLAND SUBENVIRONMENTS AND ASSOCIATED HABITATS

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Abstract: Detailed and accurate topography is fundamental information needed for understanding the dynamics of habitat distribution on low-lying barrier islands. Digital elevation models (DEM's) derived from airborne lidar are helping to quantify the relationship between habitat type and height relative to sea level. Such a DEM of a section of Matagorda Island, a sandy barrier island on the Texas coast, was acquired and compared to a map of habitats manually developed from color infrared aerial photography and field visits. Average elevations of the intertidal and upland habitats have a total range of less than 2 m. Habitat elevations are separated in an expected vertical sequence, but standard deviations show overlap between environments indicating that elevation is not the only controlling factor on habitat type and that vegetation affects the lidar elevations. The average elevation of low marsh areas was only 0.22 m above the water level of ponds interior to the relict flood-tidal delta in the study area. Sedimentation rates are expected to be very low in these areas with no open-water communication with the bay. Thus a rise in relative sea level of just 0.22 m will expand the ponds and have a profound effect on the marshes. Based on sea-level rise in the bay since the 1950's, this amount of rise is expected to occur during the next 55 years. Lidar DEM's are useful to model changes in marsh distribution and as additional and independent data layers for mapping barrier island habitats in conjunction with other remote sensing imagery.

INTRODUCTION

Depositional subenvironments of barrier island systems are the substrates for various types of wetland, aquatic, and upland habitats. Individual subenvironments and associated habitats are closely linked to their elevation relative to sea level through the processes that form and maintain

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them. On the low-lying sandy barrier islands of the micro tidal (tide range 0.6 m on the open coast and less than 0.3 m in the bays) Texas coast a small rise in relative sea level can cause conversion of fringing low marshes and flats to open water, and high marshes and flats to low marshes. Freshwater wetlands in the back barrier environments reside in relict swales, channels, and blowouts. The amount and frequency of flooding of these environments are tied to the level of the water table, which is dependent on rainfall and height above sea level. Foredunes on the open ocean side may begin to form or grow only when the beach has widened and aggraded high enough (0.6 m) above sea level so that there is a source of dry sand (Morton et al., 1994). Given the relationship of barrier island subenvironments to elevation, it stands to reason that the mapping of barrier island habitats would benefit from detailed and accurate topographic maps. Furthermore, habitat change scenarios could be devised for given sea-level changes using the topographic maps. Through manual classification of aerial photography, the generation of a lidar-derived digital elevation model (DEM), and field checks, we are quantifying the topographic relationships of barrier island habitats.

FIELD AREA

The field area is 20 km^2 of the southwest end of Matagorda Island, an undeveloped barrier island on the central Texas coast (Fig. 1). This area comprises an open-ocean sandy beach, multiple dune lines, ridge and swale topography, back barrier stabilized and active dune fields, relict recurved spits and tidal channels, and a large relict washover/flood tidal delta fan (Fig. 2) (Wilkinson, 1973). The area is now part of the Matagorda National Wildlife Refuge, but it served as an air force bombing range in the past. No urban development has occurred on the island and the only development present now includes decommissioned runways, a few buildings, and ditches and dikes. The U.S. Fish and Wildlife Service conducts periodic controlled burns of sections of the field area at a time.

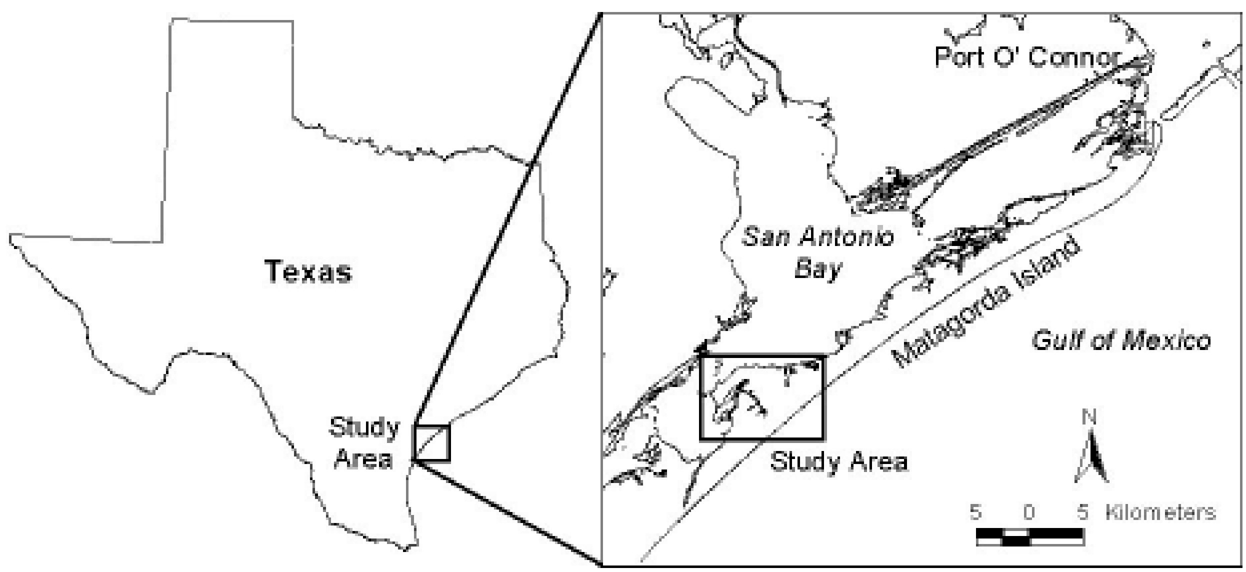

Fig. 1. Location map of study area.

Fig. 2. Aerial photograph of the study area looking northwesterly toward San Antonio Bay. The surf of the Gulf of Mexico is at the bottom.

METHODS

The distribution of wetlands and aquatic habitats is based on color-infrared aerial photographs taken in November and December 2001 (Fig. 3). Photographs were scanned to create digital images with a pixel resolution of 1 m and registered to U.S. Geological Survey digital orthophoto quarter quandrangles. Mapping of wetlands and aquatic habitats was accomplished through interactive, on-screen digitization at a scale of 1:8,000. Wetlands were classified in accordance with *Classification of Wetlands and Deepwater Habitats of the United States* by Cowardin et al. (1979). This is the classification used by the U.S. Fish and Wildlife Service for delineating wetlands as part of the National Wetlands Inventory. Marshes and tidal flats were subdivided into low and high topographic areas by interpreting water regimes, or frequency of flooding, but not through the use of the DEM described below.

The University of Texas at Austin (UT) conducted an airborne lidar survey of the study area during March 2002. UT's ALTM 1225 scanning lidar system manufactured by Optech Inc. was used for the survey. Parallel flight lines were flown at an altitude of 800 m and with 60 percent or more overlap between lines. The ALTM 1225 was operated at a rate of 25,000 pulses per second, and the laser scanned 20 degrees to each side. To improve accuracy, however, only data points with a scan angle of 18 degrees or less were processed. Even with the narrower ground swath resulting from the smaller allowable scan angle, the study area was covered twice resulting in point spacing closer than 1 m. An old runway in the study area served as a calibration target, which was surveyed during each of the six mapping flights. Vertical accuracy, as determined from point comparisons of the lidar and ground survey points of the runway calibration target, is 0.05 m (RMS) (Table 1). No attempt was made to classify points as representing either substrate or vegetation. The ALTM 1225 records two ranges for each outgoing laser pulse. These ranges are for the first and last reflected pulses of light energy. For this study, only the data from the last pulses were used. The diameter of the laser spot on the ground was about 0.2 m.

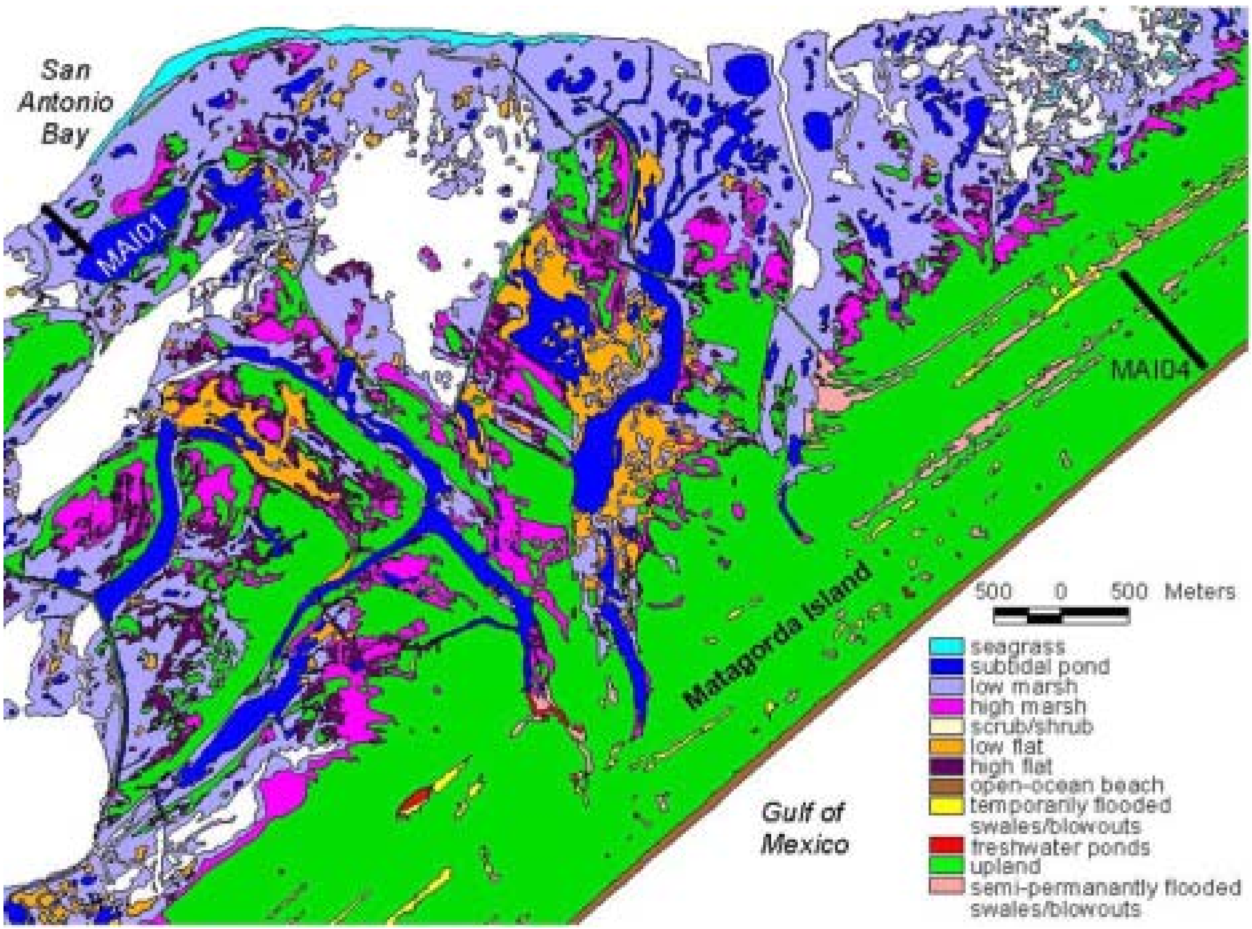

Fig. 3. Habitat classification map developed by interpretation of color infrared photography and field visits.

A DEM with a 1-m grid was generated from the lidar data points by interpolating using the TOPOGRID module in ArcInfo software version 8.0.1 (Fig. 4). TOPOGRID uses the ANUDEM interpolation method of Hutchinson (1989). To ensure a connected drainage structure, ANUDEM imposes a global drainage condition that attempts to remove spurious sinks. The algorithm was designed to produce accurate DEM's with reasonable drainage properties from comparatively low-detail and low-accuracy elevation and streamline datasets. To reduce smoothing and generate a sharper DEM, we ran the TOPOGRID command without the global drainage condition (enforce = off) and tightened the grid tolerances (tolerances = .5 and .1 instead of the default values of 2.5 and 1.0). After the DEM was computed, heights above the ellipsoid were transformed using the

GEOID99 model to provide orthometric heights in the NAVD 88 datum. A single local mean sea level correction was then applied using data from a nearby tide gauge in the bay. Polygons of the habitat map were used to clip the DEM, and then the mean and standard deviations of the elevations of each map unit were calculated.

Table 1. Lidar Point Accuracy*

Flight (Julian Day in 2002)	Bias, m	RMSE**, m
80, first flight	-0.0023	0.0503
80, second flight	-0.0752	0.0534
81, first flight	-0.0686	0.0561
81, second flight	-0.0564	0.0529
81, third flight	-0.0506	0.0532
81, transects	-0.0627	0.0539
Average	-0.0526	0.0533

* Comparison with points measured by ground survey on paved runway.
** Root Mean Square Error

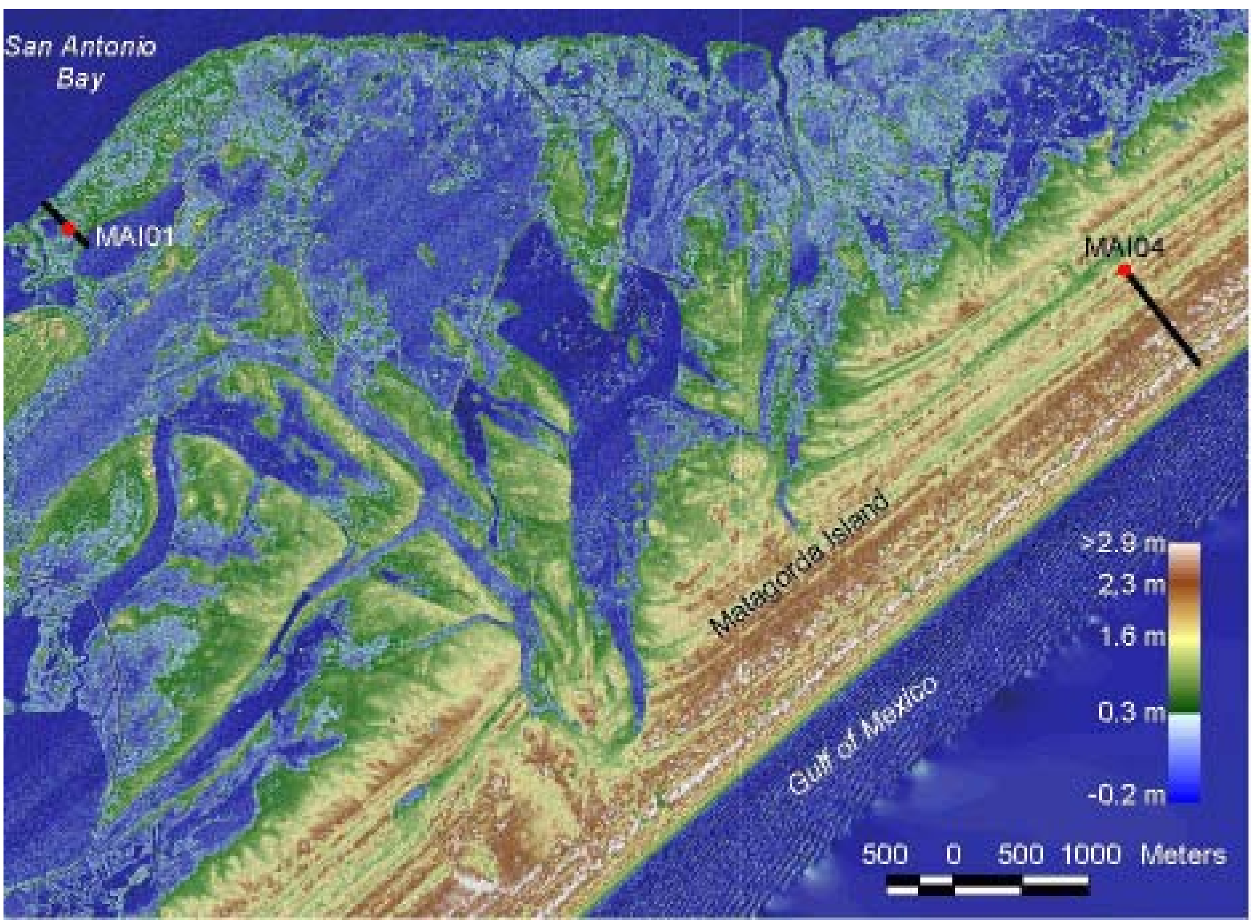

Fig. 4. Shaded relief image of digital elevation model of the study area. Banding in open-water areas is oriented parallel to the acquisition flight lines and is the result of about 0.05 m vertical error across the data swaths. The banding is only apparent on the very smooth water surface.

We conducted ground surveys in early June, 2002. During this work, we buried markers for 2 transects and conducted static geodetic GPS surveys to determine their positions. Topographic transects were measured relative to the markers using an electronic total station. Along the transects, the type of vegetation was described and the vegetation height was measured. Photographs were also taken and referenced to each topographic station.

RESULTS

Figure 5 is a plot of the mean elevations and standard deviations of the habitats mapped from the aerial photography. The units are arranged along the *x*-axis in the expected order of increasing elevation, and it is apparent that the DEM is in accordance with this. The range in mean elevation is less than 2 m, and elevation differences are very subtle and overlap among habitats. It should be noted that the lidar did not penetrate water; thus the sea-grass elevation is actually the surface of the bay water during the time of the lidar survey. The same is true for the subtidal ponds, which are interior to the washover fan/flood tidal delta complex and have no channels for communication with the bay, and the freshwater ponds and flooded swales and blowouts interior to the upland area. There is also a lack of data in places with a smooth water surface. This is caused by a specular reflection away from the aircraft which means no energy is returned for scan angles exceeding a few degrees from nadir.

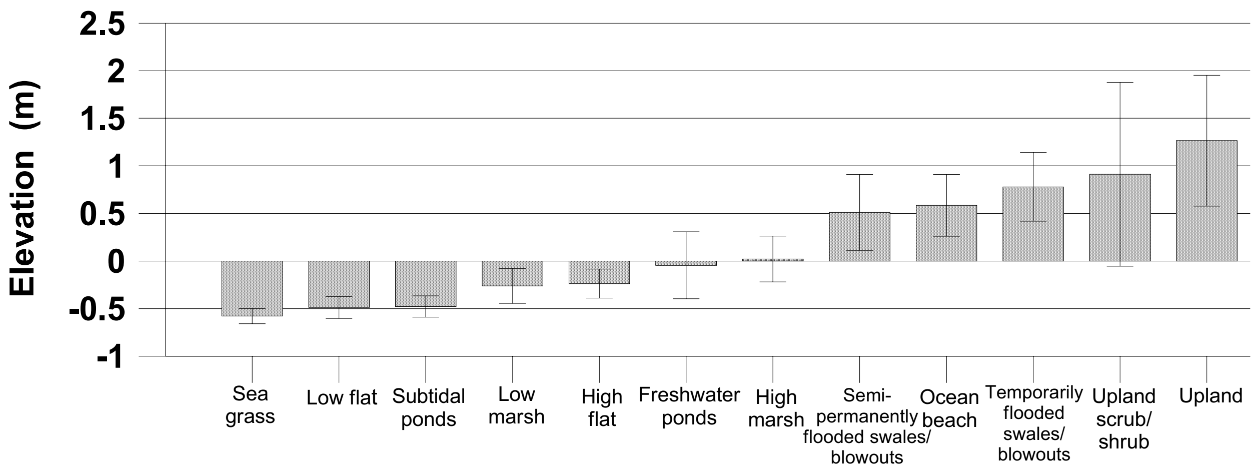

Fig. 5. Average heights and standard deviations above mean sea level for barrier island habitats.

At least some of the overlap and high standard deviations are caused by vegetation. The upland scrub/shrub unit, for example, is affected by some of the lidar points reflecting from the tops of high vegetation. Greater relief caused by ridges and swales, dunes, and blowouts, however, is probably mostly responsible for the higher standard deviations in the upland units. Mean elevations gradually increase from sea grass to high marsh and from flooded swales and blowouts to upland, but there is an abrupt change of 0.49 m between these intertidal and supratidal environments.

Figure 6 is a plot of the MAI01 ground transect (see Figs. 3 and 4 for location). The ground elevation, vegetation height, and lidar data points (not DEM values) that are within 1 m horizontal distance of the transect line are shown. Figure 7 is taken along the transect and shows the low marsh environment dominated by 0.2- to 0.3-m high *Batis maritima*. Vertically, the lidar data points fall within the vegetation cover and 0.1 to 0.2 m above the ground elevation in low marsh areas and 0.2 to 0.6 m above ground in the upland area. Furthermore, it is evident that the vertical scatter caused by the vegetation cover in the low-marsh area masks morphology with relief of less than 0.2 m occurring across horizontal scales of 10 m or less.

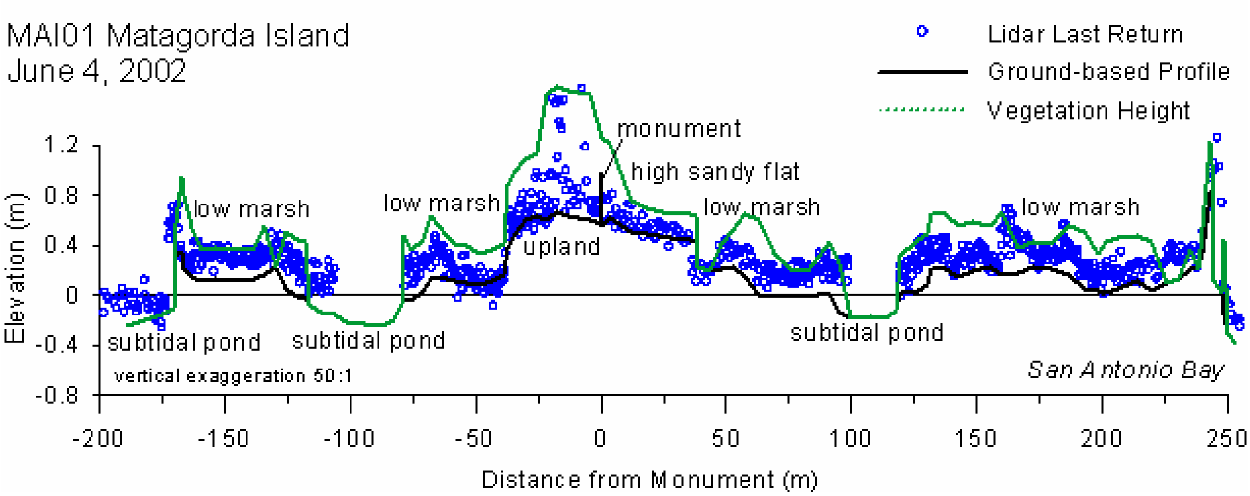

Fig. 6. Ground surveyed substrate and vegetation height relative to mean sea level. Lidar data points within a horizontal distance of 1 m from the transect are also plotted. See Figures. 3 and 4 for location.

Fig. 7. Photograph looking toward San Antonio Bay (northward) along transect MAI01 from -80 m position as shown in Fig. 6. Pond is in foreground and is bordered by low marsh dominated by *Batis maritima*. In the distance is an upland area with *Spartina spartinae* and low mesquite trees.

DISCUSSION

One of the most difficult and important delineations to make in mapping barrier island habitats are the boundaries between low and high marshes and between tidally influenced and upland environments. Analysis of the DEM shows that topography derived from lidar data is accurate and detailed enough to serve as an independent and physically meaningful layer in manual procedures or automated routines that use other remote sensing data such as multispectral or hyperspectral imagery. Vegetation causes biases and scatter in the lidar point data resulting in standard deviations that overlap between environments. However, vegetation is not the only contributing factor to overlapping elevations. Proximity to and amount of communication with bay waters may also control the development of low or high marsh, flats or uplands.

Figure 5 indicates the sensitivity of the various environments to elevation above sea level. The average elevation of low marsh areas was only 0.22 m above the water level of subtidal ponds. The rate of relative sea-level rise from the 1950's through 1993 was 0.004 m/yr as measured at a nearby bay-side tide gauge (Rockport, Texas) (White et al., 2002). Thus if sedimentation in the marshes does not keep up with sea level rise, the interior ponds will expand to cover a significant portion of the current low marsh areas in just 55 years (0.22 m / 0.004 m/yr). Sedimentation rate data are not available for the study area, but it is hypothesized that the rate is very low for the interior low marsh areas adjacent to subtidal ponds that have no open-water communication with the bay. Furthermore, these ponds with bordering low marsh areas are distributed throughout the fan complex (Fig. 3), and this type of setting is common along the backsides of barrier islands of the central and southeast Texas coast. Some of the marsh loss will be offset by conversion of high marsh to low marsh and uplands to high marsh, but more topographic modeling will be required to determine this effect.

Reducing the scattering and bias effects of the vegetation on the lidar points would make the lidar more useful in barrier island settings. As mentioned above, the lidar instrument used for this survey recorded two ranges for each outgoing laser pulse. The resolution of these measurements, however, does not allow distinguishing ranges that are within several meters of each other. This is useful in a tall tree canopy, but not for low vegetation typical of the study area. For this reason, our future work includes adding a full wave-form digitizer to the lidar instrument. The digitizer will record the wave form of the reflected laser pulse at increments equivalent to about 0.15 m distance. With the digitizer, we anticipate we will improve our determination of where the substrate is below vegetation and the structure of the vegetation.

CONCLUSIONS

1. Detailed and accurate lidar DEM's may serve as a truly independent and physically meaningful data layer for mapping barrier island habitats in conjunction with other data types such as multispectral or radar imagery.
2. In areas where sedimentary processes are not significant and a rise in sea level can be expected to simply inundate the existing terrain, lidar DEM's can help predict the change in habitats during particular sea-level-rise scenarios.
3. In barrier island settings along the Texas coast, a relative sea-level rise of just 0.2 m will have a profound effect on the distribution of wetland habitats. Based on tide gauge records since the 1950's, this amount of sea-level rise is expected to occur during the next 55 years.

4. Vegetation causes scatter in the lidar point data and biases the data to be above the substrate. Full wave-form digitization of the reflected laser pulse is one way being pursued to lessen the vegetation effect.

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REFERENCES

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T., 1979, Classification of wetlands and deepwater habitats of the United States: U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C., USA 131 p.

Morton, R. A., Paine, J. G., and Gibeaut, J. C., 1994, Stages and durations of post-storm beach recovery, southeastern Texas coast, U.S.A.: Journal of Coastal Research, v. 10, no. 4, p. 884 – 908.

White, W. A., Tremblay, T. A., Waldinger, R. L., and Calnan, T. R., 2002, Status and Trends of Wetland and Aquatic Habitats on Texas Barrier Islands, Matagorda Bay to San Antonio Bay: Bureau of Economic Geology, John A. and Katherine G. Jackson School of Geosciences, The University of Texas at Austin, Final Report prepared for the Texas General Land Office and National Oceanic and Atmospheric Administration under GLO Contract No. 01-241-R, 71 p.

Wilkinson, B. H., 1973, Matagorda Island – The Evolution of a Gulf Coast Barrier Complex: unpublished Ph.D. dissertation, The University of Texas at Austin, 178 p.

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Key words: lidar, wetlands, Matagorda Island, Texas, sea-level rise, barrier island, digital elevation model, habitat mapping, topography