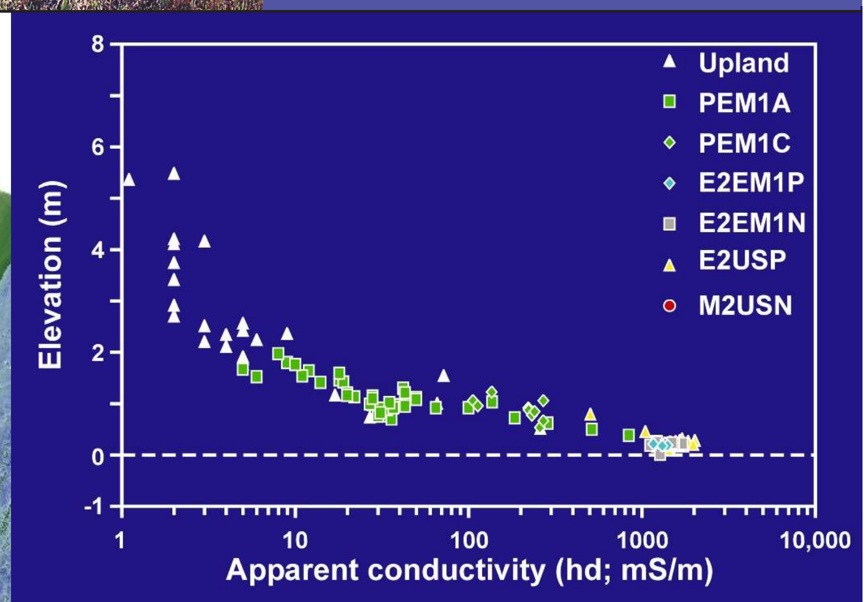
A New Look at Mustang Island Wetlands:

Mapping Coastal Environments with Lidar and EM

Jeffrey G. Paine, William A. White, and John R. Andrews

Assisted by
James C. Gibeaut, Roberto Gutierrez, Tiffany L. Hepner, Rebecca C. Smyth, and Rachel L. Waldinger



Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin
Austin, Texas 78713-8924

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SUMMARY

We combine elevation data acquired using airborne lidar, conductivity measured using electromagnetic (EM) induction, and vegetation surveys to examine whether topography and ground conductivity can be used to map coastal wetland vegetation assemblages. In 2003, we used airborne lidar to acquire elevation data along two transects across Mustang Island, a modern coastal barrier on the central Texas coast. We combined the centimeter-scale elevations with ground-based conductivity measurements and vegetation surveys acquired at 20-m spacings from the gulf beach to the bay shore. It has long been known that wetland vegetation responds to both elevation and salinity; because ground conductivity is strongly influenced by soil salinity, we used EM induction measurements as a salinity proxy. Elevation and conductivity information, acquired either on the ground or from aircraft, represent a quantitative complement to traditional wetland mapping methods that rely upon aerial photographs and limited field checks.

Along both transects, conductivities were highly negatively correlated with elevations. Elevation and conductivity profiles correlated reasonably well with habitat mapped in the 1992 National Wetland Inventory (NWI), but showed greater detail than is depicted on the NWI maps and identified some areas where mapped wetland units are likely to be uplands and others where upland units are likely to be wetlands. Detail achievable with elevation and conductivity data was similar to that achieved in the ground-based vegetation surveys along each transect. Lowest elevations and highest average conductivities were measured in saline environments such as marine and estuarine NWI units, the forebeach, low and high salt marshes, and low and high wind-tidal flats. Highest elevations and lowest conductivities were measured in generally nonsaline environments such as upland and palustrine NWI units, fore- and back-island dunes, vegetated-barrier flats, and low and high fresh marshes.

Combined or individually, elevation and conductivity data allow better discrimination among coastal wetland environments than can be achieved from aerial photographic interpretation alone. Future work in the promising application of lidar and EM to rapid and accurate

classification of coastal environments should include evaluating the effect of dense vegetation height on the ability to accurately determine land-surface elevation, determining the magnitude of possible seasonal change in the electrical conductivity of the ground in fresh and saline coastal environments, examining the applicability of elevation and conductivity statistics obtained for coastal environments in one geographic area to classification of similar environments in other areas, and evaluating the potential benefits of using airborne EM sensors to measure ground conductivity remotely and at multiple exploration depths simultaneously.

INTRODUCTION

This study examines whether two innovative technologies—lidar (light detection and ranging) and EM (electromagnetic induction)—can improve the accuracy of wetland mapping that has historically been based chiefly on analysis of aerial photographs. Recognition of the importance of monitoring the status and trends of coastal wetlands has increased in recent decades because of our new awareness of the critical role wetlands play in the transitional aquatic-terrestrial environment and our increasing alarm at the rapid change in wetlands resulting from the rise in relative sea level. In this pilot study on Mustang Island (fig. 1), we evaluate a potentially rapid and accurate wetland-mapping approach that could complement ongoing efforts in traditional aerial photographic analysis. We are exploiting (1) the known strong relationship between elevation and marsh type by comparing a lidar-derived digital elevation model (DEM) of Mustang Island with existing wetland maps and detailed vegetation transects, and (2) another known strong relationship between soil and water salinity and marsh type by collecting and comparing EM-derived conductivity data with elevation and vegetation type along the same detailed island transects.

Data used in this project include digital maps of wetland type and distribution from the 1950s, 1979, and 1992 and DEMs derived from an airborne lidar survey of Mustang Island. We compare these data sets within a geographic information system to establish the level of agreement between the wetland maps and high-resolution DEMs, which have elevation points spaced at about 1-m intervals with a vertical accuracy of about 15 cm. We selected two representative transects across Mustang Island (fig. 2) where we surveyed vegetation type and measured the electrical conductivity of the ground. Electrical conductivity, which is closely correlated to soil and water salinity, was measured noninvasively along the transects using a ground conductivity meter. We evaluate the traditional approach to wetland mapping by comparing vegetation types extracted from the most recent wetland maps with those determined along the island transects. We evaluated the lidar and EM approach by examining the relationship along each transect

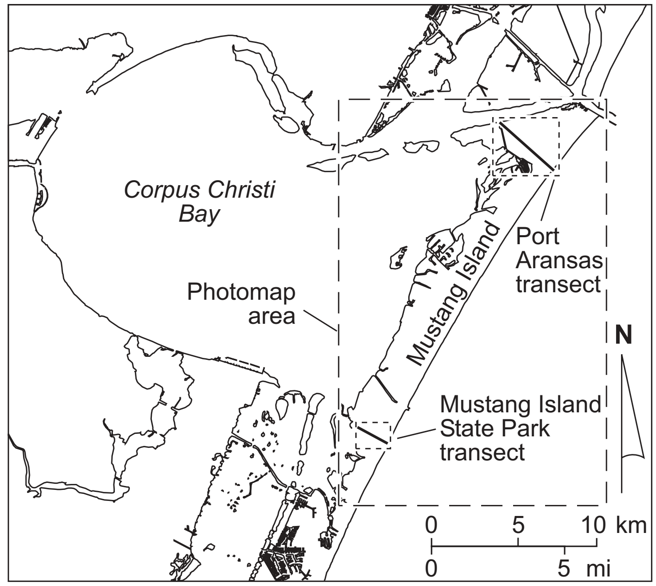

Figure 1. Location of the Mustang Island study area, Texas Gulf Coast.

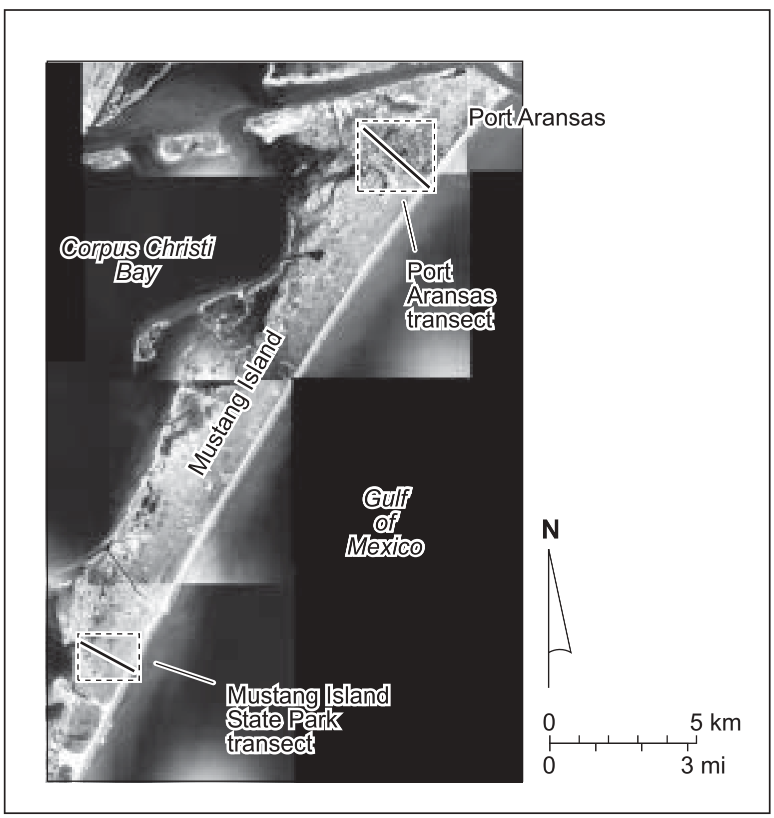

Figure 2. Map of the Mustang Island area showing locations of the aerial photographic maps and the Mustang Island State Park (MISP) and Port Aransas (PA) transects.

between lidar-derived elevation, measured ground conductivity, and vegetation type determined during the ground surveys.

HABITATS AND COASTAL ENVIRONMENTS

We analyzed the relationship between elevation, conductivity, and coastal vegetation assemblages using two classification systems: that used by the U.S. Fish and Wildlife Service (USFWS) in the National Wetland Inventory (NWI) program, and that used by the Bureau of Economic Geology (Bureau) in its detailed mapping that includes wetlands and other associated coastal environments. We used habitats mapped on 1992 NWI maps and coastal environments mapped along the island transects for comparison with elevation and conductivity data.

Beach

Beaches lie along the gulf shoreline of Mustang Island and include the forebeach, which is subject to daily wave swash and tidal inundation, and the backbeach, which is inundated less frequently by spring and storm tides (figs. 3 and 4). Scattered vegetation may occur along the backbeach, but this unit is typically barren of vascular plants. In the Cowardin and others (1979) classification that forms the basis of the USFWS NWI program, gulf beaches are classified and mapped as marine intertidal unconsolidated shore (M2US). Water-regime modifiers used in this classification would be regularly flooded (N) for the forebeach (M2USN), and irregularly flooded (P) for the backbeach (M2USP).

Dune

Along the backbeach are isolated coppice dunes, behind which are well-vegetated fore-island dunes and dune ridges (figs. 3 and 5). In addition, past active dunes have migrated bayward and have become vegetated and stabilized at various locations on the island. Mid- and

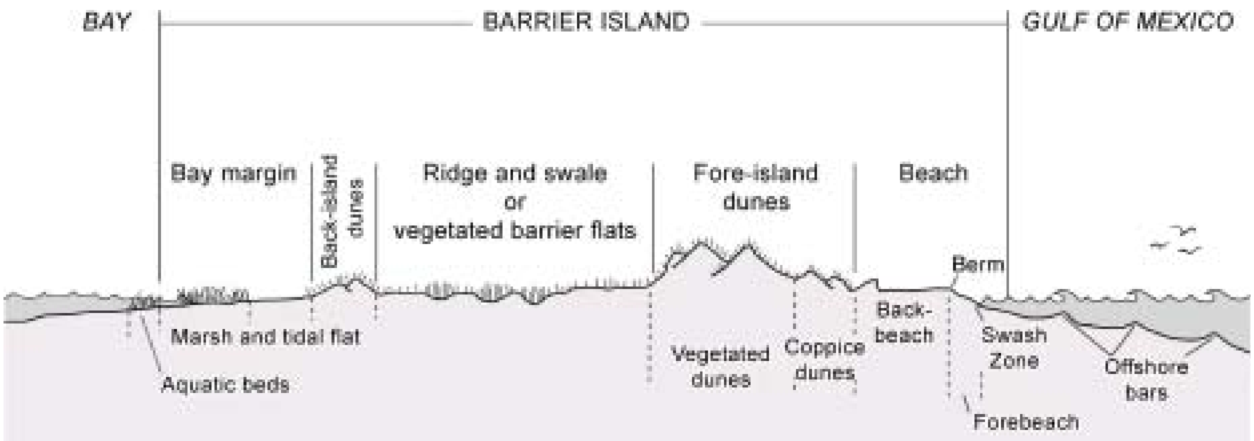

Figure 3. Profile of a barrier island showing features that may be present from the gulf to the bay shoreline.

Figure 4. Topographically low, regularly flooded forebeach and higher irregularly flooded backbeach, MISP transect (waypoint 112). The conductivity meter (Geonics EM38) used to measure apparent ground conductivity is shown on the beach.

(a)

(b)

Figure 5. (a) Fore-island dune ridge on the MISP transect (waypoint 107), and (b) second dune ridge near the PA transect. Dune vegetation includes croton punctatus, sea oats, bitter panicum, marshhay cordgrass, bushy bluestem, little bluestem, camphor weed, prickly pear, and other species.

back-island dunes were encountered on the two transects. Typical vegetation on the vegetated fore-island dunes includes bitter panicum (Panicum amarum), sea oats (Uniola paniculata), beach tea (Croton punctatus), sea purslane (Sesuvium portulacastrum), goatfoot morning-glory (Ipomoea pescaprae), and fiddleleaf morning-glory (Ipomoea stolonifera). Vegetation on the back side (bayward) of fore-island dunes and on stabilized mid- and back-island dunes includes saltmeadow cordgrass (Spartina patens), dune paspalum (Paspalum monostachyum), bushy bluestem (Andropogon glomeratus), little bluestem (Schizachyrium scoparium var. littorale), camphor weed (Heterotheca subaxillaris), Indian blanket (Gaillardia pulchella), prickly pear cactus (Opuntia sp.), and others. Dunes are classified as uplands (U) on USFWS NWI maps.

Vegetated-Barrier Flat

Vegetated-barrier flats (VBFs) are hummocky, and grass-, forb-, and shrub-covered sandy areas of low relief that generally lie between the fore-island dunes and bay marshes and tidal flats (figs. 3 and 6). The hummocky nature of this land reflects its origin as low dunes and mounds, deflation flats, accretionary flats, and washover deposits. Vegetation includes dune paspalum, bushy bluestem, little bluestem, marshhay cordgrass, gulf cordgrass (Spartina spartinae), camphor weed, pennywort (Hydrocotyle bonariensis), white-topped sedge (Dichromena colorata), sea-oxeye (Borrichia frutescens), bigleaf sumpweed (Iva frutescens), frog-fruit (Phyla sp.), Indian blanket, marsh fimbry (Fimbristylis castanea), bristle grass (Setaria sp.), prickly pear, and others. VBF is generally mapped as upland (U) on NWI maps.

Fresh-Water and Non-Tidal Marsh

Fresh-water marshes, or interior non-tidal marshes, form in depressions typically surrounded by dunes and VBF (fig. 7). The depressions may be formed by natural processes such as wind deflation and scouring of sand during storms, or by artificial processes such as sand quarrying. Marshes that are regularly flooded and wet with standing water are typically classified as (topo-

(a)

(b)

Figure 6. Vegetated-barrier flat (a) along the MISP transect (waypoint 61), and (b) along the PA transect (waypoint 117). Vegetation includes bushy bluestem, little bluestem, marshhay cordgrass, gulf cordgrass, camphor weed, scattered three-square bulrush, and other species.

(a)

(b)

Figure 7. Interior fresh-water marshes on the MISP transect (a) where the predominant vegetation is cattail along State Highway 361 (waypoint 76), and (b) where vegetation is dominated by three-square bulrush (waypoint 84).

graphically) low marshes. On NWI maps the low marshes are classified as palustrine emergent wetlands, persistent vegetation, semipermanently flooded (PEM1F) or seasonally flooded (PEM1C). Common vegetation in these habitats includes cattail (Typha spp.), three-square bulrush (Scirpus pungens), seashore paspalum (Paspalum vaginatum), spikerush (Eleocharis spp.), coastal-water hyssop (Bacopa monnieri), Drummond's rattle-bush (Sesbania drummondii), seashore dropseed (Sporobolus virginicus), frog-fruit, marsh fimbry, and others. Fresh-water marshes flooded less frequently are classified as high marsh, or in the NWI classification as temporarily flooded palustrine marsh (PEM1A) and at some locations PEM1C. Vegetation may include three-square bulrush, spikerush, gulf cordgrass, marshhay cordgrass, sea-oxeye, pennywort, and others.

Fresh and Non-Tidal Pond

Depressions that pond water in interior areas that are not affected by tides and have little to no emergent vegetation are designated as ponds or interior water bodies. The NWI classification for these areas is usually palustrine unconsolidated bottom with a semi-permanently flooded water regime (PUBF) or permanently flooded water regime (PUBH).

Salt- and Brackish-Water Marsh

Salt- and brackish-water marshes generally occur in back-island areas where the land is low enough to be inundated periodically by tides. Low salt- and brackish-water marshes are vegetated by various vascular plants including smooth cordgrass (Spartina alterniflora), saltwort (Batis maritima), perennial glasswort (Salicornia virginica), shoregrass (Monanthochloe littoralis), black mangrove (Avicennia germinans), and others (figs. 8 to 11). The NWI classification designates these areas as estuarine intertidal emergent wetlands with persistent vegetation and regularly flooded tidal water regimes (E2EM1N). Topographically higher marshes commonly have vegetation characterized by sea-oxeye, marshhay cordgrass, gulf cordgrass, seashore dropseed,

Figure 8. Salt-water marsh on the PA transect (waypoint 189). The predominant vegetation is saltwort.

Figure 9. Low salt-water marsh (smooth cordgrass) on the MISP transect (waypoint 48).

Figure 10. Salt-water marsh near PA transect (waypoint 183). Vegetation includes black mangrove shrubs, smooth cordgrass, saltwort, and glasswort.

Figure 11. Salt-water marsh and tidal flat near MISP transect (waypoint 21). Vegetation is mostly shoregrass. Algae drapes plant stubs on margins of vegetated areas.

shoregrass, annual glasswort, bigleaf sumpweed, marsh fimbry, Carolina wolfberry (Lycium carolinianum), and locally three-square bulrush. The NWI classification for these higher marshes is estuarine intertidal emergent wetlands, persistent vegetation, with irregular tidal flooding (E2EM1P).

Wind-Tidal Flats

Wind-tidal flats are tidal flats that are inundated by estuarine waters elevated by astronomical tides and by wind-induced and storm tides. Lower tidal flats that are regularly flooded by tides typically contain algal mats that produce darker signatures on aerial photographs (fig. 12). These flats may be vegetated annually by scattered annual glasswort but usually are barren of vascular plants. These topographically low lands have an NWI classification of estuarine intertidal unconsolidated shore with a regularly flooded tidal water regime (E2USN). The topographically higher flats are flooded less frequently, and are usually brighter white on aerial photographs. They are classified as E2USP (P = irregularly flooded) in the NWI classification. There has been a loss of wind-tidal flats on Mustang Island since the 1950s (White and others, 1998).

Estuarine Water Bodies

Corpus Christi Bay, which borders Mustang Island, is the source of back-island tides and is mapped as estuarine open water. Smaller tidally influenced water bodies that contain salt to brackish water in back-island areas are also mapped as estuarine open water (fig. 13). In the NWI classification, Corpus Christi Bay and other salt- and brackish-water bodies are classified as estuarine subtidal unconsolidated bottom with a subtidal water regime (E1UBL).

(a)

(b)

Figure 12. Wind-tidal flats covered with algal mats (a) along and (b) adjacent to the PA transect (waypoint 191).

Figure 13. Estuarine water bodies in distance, fringed by smooth cordgrass intergrading with saltwort in foreground, on PA transect (waypoint 180).

METHODS

We combined elevation information derived from a 2003 airborne lidar survey of parts of Mustang Island with ground conductivity measurements and a vegetation survey acquired along the Mustang Island State Park and Port Aransas transects (fig. 2) across the island. We compared elevation and ground conductivity data with vegetation assemblages and coastal barrier environments as determined from the vegetation survey and as depicted on standard wetland maps published as part of the NWI to determine whether remote methods such as lidar and ground-based or airborne EM can help improve the detail, accuracy, and timeliness of wetland inventories.

Lidar Survey

The Bureau acquired airborne light detection and ranging (lidar) data along two transects across Mustang Island, Texas (fig. 2). One transect crosses the southwest part of the island at Mustang Island State Park. The other transect is located southwest of Port Aransas. The purpose of this mapping was to evaluate the usefulness of lidar to delineate extents of coastal habitats based on subtle topographic changes. Data sets include DEMs created from lidar point data. The DEMs lie within five U. S. Geological Survey 7-1/2 minute quadrangles between Port Aransas on the northern end of Mustang Island and Padre Island National Seashore on the southwest.

Lidar digital elevation points are computed using three sets of data: laser ranges and associated scan angles, platform position and orientation, and calibration and mounting parameters (Wehr and Lohr, 1999). Global Positioning System (GPS) receivers in the aircraft and on the ground provide platform positioning data. The GPS receivers record pseudo-range and phase information for post-processing. Platform orientation information comes from an inertial measurement unit (IMU) containing sets of three orthogonal accelerometers and gyroscopes. An aided-inertial navigation system (INS) solution for the aircraft's attitude is estimated from the IMU output and the GPS information.

The DEMs were derived from lidar x-, y-, and z- point data generated by combining laser range and aircraft attitude data collected using an Optech Inc. Airborne Laser Terrain Mapper (ALTM) 1225 with once-per-second data collected using geodetic quality GPS airborne and ground-based receivers. The Bureau's ALTM 1225 system was installed in a single-engine Cessna 206 and flown from the Aransas County Airport in Fulton, Texas. The lidar data were collected during two flights on September 18 and October 31, 2003. Lidar instrument settings and flight parameters were: (1) laser pulse rate 25 kHz, (2) scanner rate 35 Hz, (3) scan angle ±15 degrees, (4) flight altitude 450 to 665 m, and (5) ground speed 90 to 110 kt. At least two GPS base stations were operated during each flight.

We produced DEM swaths more than 300-m wide from the gulf beach to the bay shore for the Mustang Island State Park and Port Aransas transects. Horizontal coordinates are in the Universal Transverse Mercator projection using the 1983 North American Datum, zone 14, 1980 Geodetic Reference System. Elevations are relative to the 1988 North American Vertical Datum (NAVD). Lidar-derived elevations have horizontal and vertical accuracies estimated at 0.01 to 0.03 m from comparisons with ground GPS surveys. Horizontal agreement between the ground kinematic GPS and the lidar was within the resolution of the 1 m x 1 m DEM.

The lidar data were sorted to extract points within 0.5 m of a ground GPS survey point. The mean difference between elevations derived from lidar and ground GPS was used to estimate and remove an elevation bias from the lidar. The standard deviation of these elevation differences provides an estimate of the lidar precision of 0.13 ± 0.04 m. After removing vertical biases from each flight, a vertical uncertainty of 0.04 m (root mean square) remains.

We produced detailed elevation profiles along each transect (app. A and B) for comparison with wetland maps, vegetation surveys, and conductivity measurements, and generated averaged elevations for all lidar data points within 1.5 m of a transect station where we also measured ground conductivity and vegetation abundance, type, and height.

EM Survey

We used the frequency-domain EM method to measure apparent electrical conductivity along the Mustang Island State Park and Port Aransas transects (fig. 2). Frequency-domain EM methods employ a changing primary magnetic field created around a transmitter coil to induce current to flow in the ground, which in turn creates a secondary magnetic field that is sensed by the receiver coil (Parasnis, 1973; Frischknecht and others, 1991; West and Macnae, 1991). The strength of the secondary field is a complex function of EM frequency and ground conductivity (McNeill, 1980b), but generally increases with ground conductivity at constant frequency.

We used a hand-held Geonics EM38 ground conductivity meter (fig. 4) to measure the apparent conductivity of the ground. This instrument operates at a primary frequency of 14.6 kHz, measuring apparent conductivity to a depth of about 0.8 m (horizontal dipole [hd] orientation) and 1.5 m (vertical dipole [vd] orientation). The instrument has a useful conductivity range of less than 1 millisiemen/m (mS/m) to more than 1,000 mS/m.

We acquired ground conductivity measurements at 234 sites on Mustang Island between December 3 and 5, 2004 (app. A and B). For the Mustang Island State Park and Port Aransas transects, we measured apparent conductivity in the hd and vd orientations at stations spaced 20-m apart from the gulf beach to the bay shore or its associated tidal flats. We supplemented regularly spaced measurements with additional readings within distinct environments or at boundaries between environments along each transect.

Where the apparent conductivity of the ground was within the instrument's range, we recorded measurements with the instrument on the ground. In areas where apparent conductivity approached or exceeded the upper limit of the instrument's range, we made one set of measurements with the instrument on the ground (which in some cases exceeded the range of the instrument) and another set with the instrument at a fixed height of 0.6 m above the ground. We then corrected the out-of-range values by extrapolating the lower apparent conductivities recorded with the instrument at a fixed height according to the empirical relationship observed between the ground-based and fixed-height measurements made over ground having lower apparent conductivities. These corrected values were used for comparison with transect elevation and vegetation surveys.

In the hd orientation, we determined an empirical, statistical relationship between ground-level measurements and raised-instrument measurements using 22 data pairs that had apparent conductivities at ground level of less than 1400 mS/m (fig. 14). The relationship,

(sigma g) = 4.03 x (sigma r) - 85.5,

where sigma g is the apparent conductivity at the ground surface and sigma r is the apparent conductivity with the instrument 0.6 m above the ground surface, gives an r squared value of 0.97. We used this relationship to extrapolate a corrected ground-level apparent conductivity in the hd orientation from the raised-instrument conductivity where the measured conductivity at ground level exceeded 1400 mS/m, the instrument's maximum linear limit in this orientation.

In the vd orientation, we determined a similar relationship between ground-level measurements and raised-instrument measurements using 24 data pairs that had apparent conductivities at ground level of less than 1300 mS/m (fig. 15). This relationship,

(sigma g) = 1.89 x (sigma r) + 34.7,

gives an r squared value of 0.95. We used this formula to extrapolate a corrected ground-level apparent conductivity in the vd orientation from the raised-instrument conductivity where the measured conductivity at ground level exceeded 1300 mS/m, the instrument's maximum linear limit in this orientation.

Vegetation Survey

At each transect location (app. A, B, and C), we recorded the following in the field: plant species (dominant listed first), percent cover, range in vegetation height, average height of the vegetation "mass" (height of the thickest accumulation), and water regime (dry, moist, wet, very wet, or depth of standing water). Digital aerial photographs were used along with field notes to

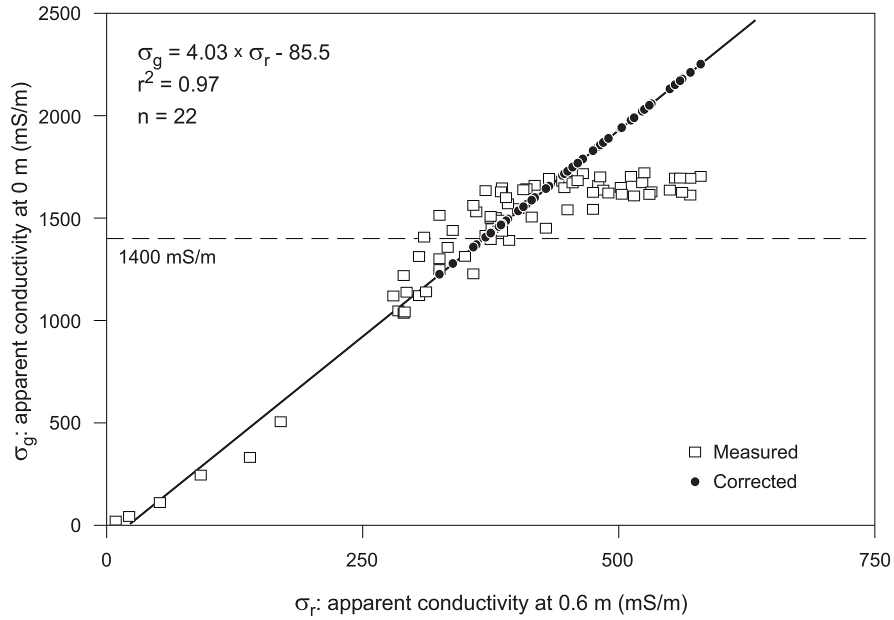

Figure 14. Relationship between apparent conductivity measured in the horizontal dipole orientation at an instrument height of 0.6 m above ground (sigma r) and apparent conductivity measured at the ground surface (sigma g) using only ground-height measurements below 1400 mS/m. The best-fit equation was used to correct ground-height measurements that exceeded the upper limit of the Geonics EM38 ground-conductivity meter.

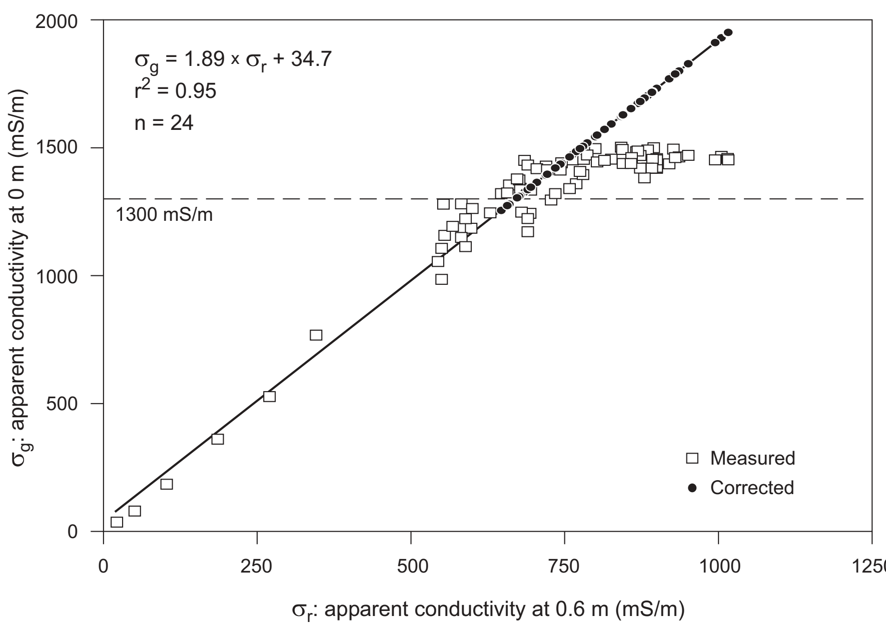

Figure 15. Relationship between apparent conductivity measured in the vertical dipole orientation at an instrument height of 0.6 m above ground (sigma r) and apparent conductivity measured at the ground surface (sigma g) using only ground-height measurements below 1400 mS/m. The best-fit equation was used to correct ground-height measurements that exceeded the upper limit of the Geonics EM38 ground-conductivity meter.

classify the locations into one of the following coastal environments: beach (or berm), dune, VBF, fresh-water and non-tidal marsh, fresh and non-tidal pond, salt- to brackish-water marsh, wind-tidal flat, and estuarine water.

MUSTANG ISLAND STATE PARK TRANSECT

The Mustang Island State Park (MISP) transect is located on the southwest part of Mustang Island (figs. 2 and 16). This transect extends 2.2 km from the gulf beach to the Corpus Christi Bay shore. We surveyed vegetation and measured apparent conductivity at 112 locations along this transect (app. A and C) and obtained elevations at these locations from a DEM (fig. 17) constructed from lidar data acquired in 2003 along a swath about 350 m wide that was centered on the transect.

Wetland Units and Coastal Environments

To compare our vegetation, elevation, and conductivity results with existing habitat data, we used a geographic information system to extract transect locations that occur within units mapped on the 1992 NWI (tables 1 and 2). More than half of the transect locations are within upland (U) or palustrine (PEM1A or PEM1C) mapped units (table 2); the remainder are within either estuarine- (E2EM1P, E2EM1N, or E2USP) or marine-influenced (M2USN) units.

Boundaries between units on the NWI maps correspond reasonably well to tonal boundaries on the aerial photograph (fig. 16) and elevation changes as depicted on the DEM (fig. 17), but the units may or may not be classified accurately. Direct field observations made during this project allow greater detail and accuracy in establishing the appropriate coastal environment for a given location than is achievable on the smaller-scale, aerial photograph-based NWI maps. Comparisons between the two habitat assignments (fig. 18) show that mapped NWI units may encompass several distinct coastal environments. For example, the palustrine unit PEM1A, classified as temporarily flooded emergent persistent wetland (table 1), is mapped where ground surveys

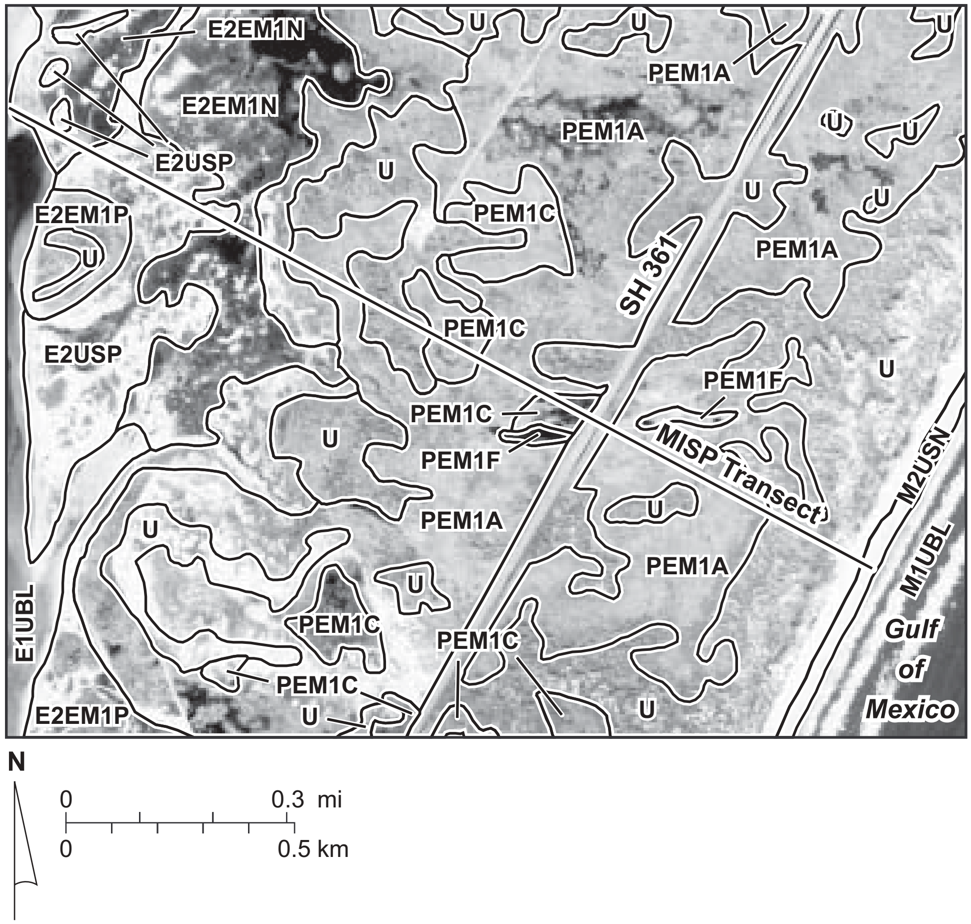

Figure 16. Aerial photomosaic of the MISP transect showing habitats identified on the 1992 National Wetland Inventory (NWI) maps. The photomosaic was compiled from aerial photographs flown in 1995 and obtained from the Texas Natural Resource Information System (TNRIS).

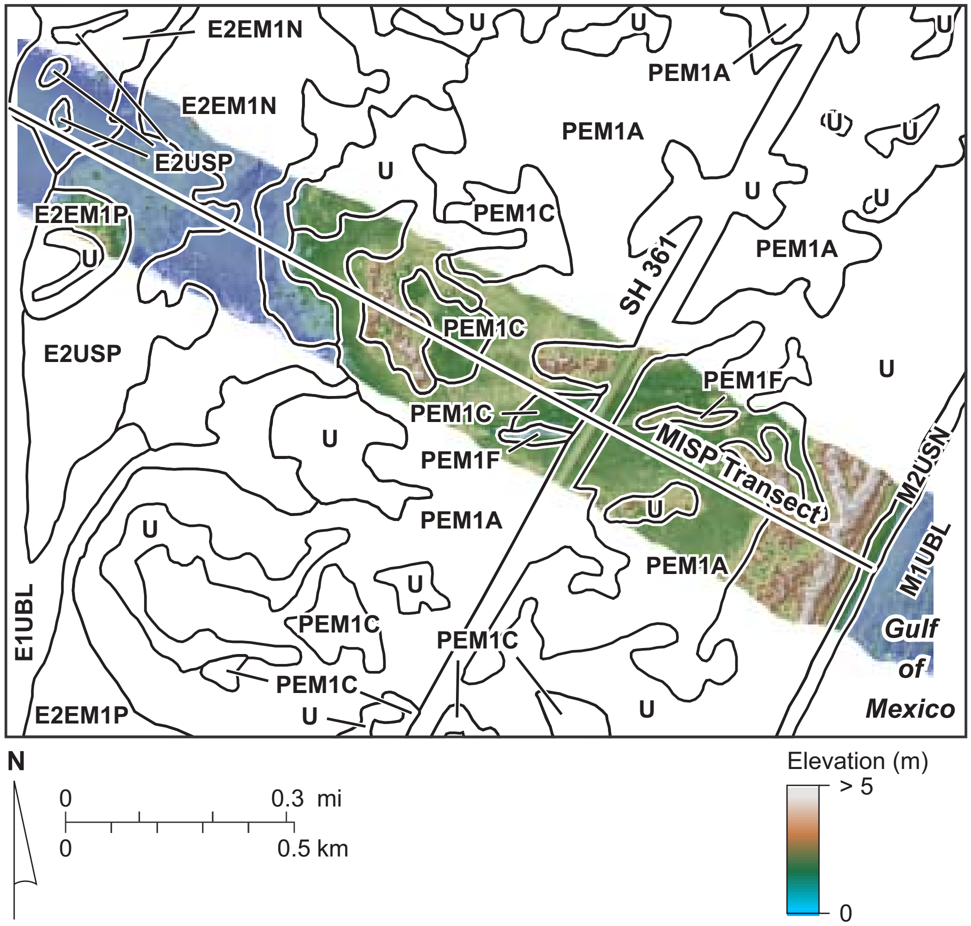

Figure 17. Digital elevation model (DEM) of the MISP transect showing habitats identified on the 1992 NWI maps. The DEM was constructed from lidar data acquired along the transect in 2003.

Table 1. Classification system (Cowardin and others, 1979) used by the U.S. Fish and Wildlife Service (USFWS) in the National Wetland Inventory (NWI). This partial list of units includes only those mapped along the Mustang Island State Park and Port Aransas transects (fig. 2).

NWI Code	Classification description	Common Description
U	Upland	Not a wetland
PEM1A	Palustrine emergent persistent wetland, temporarily flooded	Fresh or interior marsh, persistent vegetation, topographically high
PEM1C	Palustrine emergent persistent wetland, seasonally flooded	Fresh or interior marsh, persistent vegetation, topographically low
E2EM1P	Estuarine intertidal persistent emergent wetland, irregularly flooded	Salt- to brackish-water marsh, persistent vegetation, topographically high
E2EM1N	Estuarine intertidal persistent emergent wetland, regularly flooded	Salt- to brackish-water marsh, persistent vegetation, topographically low
E2AB1P	Estuarine intertidal aquatic bed, algal, irregularly flooded	Tidal and wind-tidal flats, with algal mats, topographically high
E2USP	Estuarine intertidal unconsolidated shore, irregularly flooded	Tidal and wind-tidal flats, topographically high
E2USN	Estuarine intertidal unconsolidated shore, regularly flooded	Tidal and wind-tidal flats, topographically low
E1UBL	Estuarine subtidal unconsolidated bottom, subtidal	Estuarine open water
M2USP	Marine intertidal unconsolidated shore, irregularly flooded	Backbeach along Gulf shore
M2USN	Marine intertidal unconsolidated shore, regularly flooded	Forebeach along Gulf shore

Table 2. Elevation and apparent conductivity ranges measured at 112 locations for 1992 NWI units mapped along the Mustang Island State Park transect (app. A). Elevations were measured using an airborne lidar instrument. Apparent conductivities were measured using a ground-based Geonics EM38 instrument in the vertical dipole (vd) and horizontal dipole (hd) orientations.

NWI unit	n	Elev. avg. (m)	Elev. range (m)	App. con. avg., vd (mS/m)	App. con. range, vd (mS/m)	App. con. avg., hd (mS/m)	App. con. range, hd (mS/m)
U	25	2.62	0.52-5.49	26	2-288	21	1-260
PEM1A	40	1.12	0.38-1.97	94	10-852	75	5-842
PEM1C	10	0.9	0.54-1.23	266	160-408	207	106-270
E2EM1P	3	0.2	0.18-0.22	1254	1157-1326	1293	1163-1405
E2EM1N	11	0.19	0.01-0.26	1318	1106-1592	1386	1119-1715
E2USP	21	0.26	0.1-0.8	1467	767-1783	1516	505-2021
M2USN	2	0.68	0.34-1.02	515	322-707	530	298-828

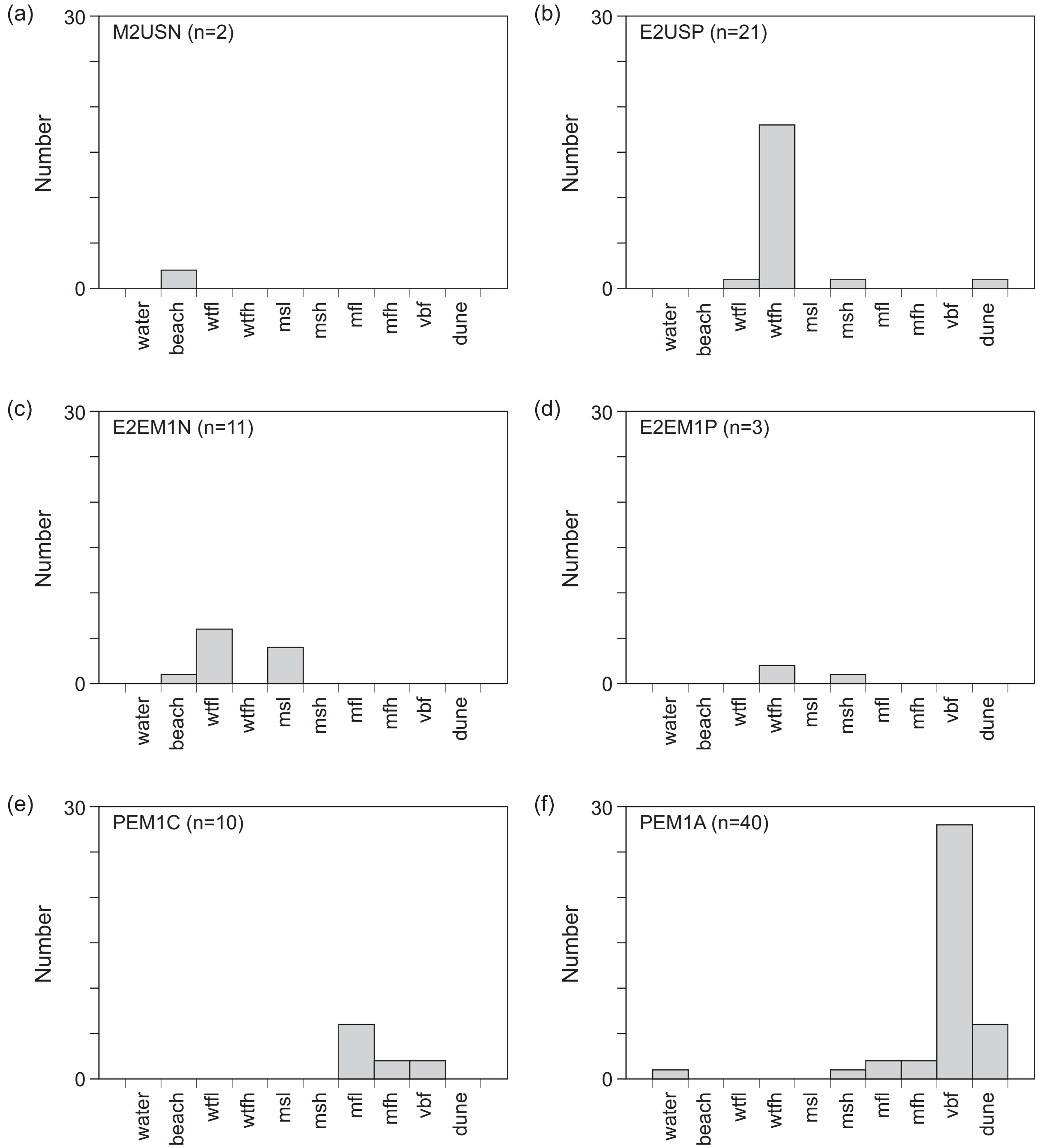

Figure 18. Distribution of coastal environments identified along the MISP transect for each 1992 NWI unit.

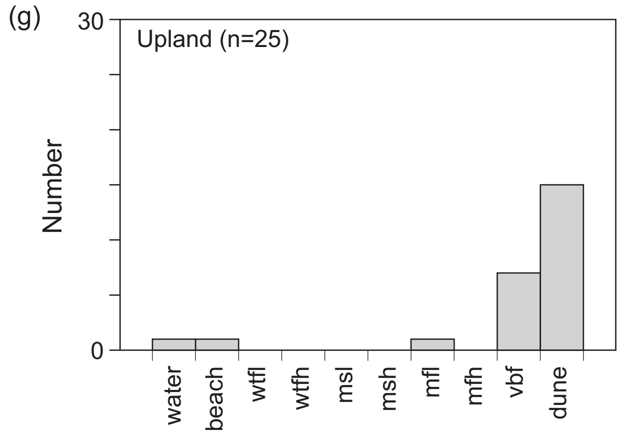

Figure 18 (continued).

identified dunes, VBF, standing fresh water, high and low fresh marsh, and high salt marsh (fig. 18f). The estuarine unit E2USP, classified as irregularly flooded intertidal unconsolidated shore (table 1), is mapped where ground surveys identified low dunes and high and low wind-tidal flats (fig. 18b). The non-wetland U (upland) category includes locations categorized as dune, VBF, low fresh marsh, beach, and standing fresh water in the ground-based survey (fig. 18g).

Elevation and Vegetation Units

Lidar-derived elevations at the 112 locations along the MISP transect range from 0.01 to 5.5 m NAVD (figs. 17 and 19, app. A). Highest elevations (2 m or more) were measured across the fore-island dunes within about 300 m of the gulf shoreline and mid-island dunes between about 800 and 1500 m from the gulf shoreline. Lowest elevations (0.3 m or less) were found bayward of the mid-island dunes to the bay shoreline.

At a third of the locations (38 of 112), vegetation was sufficiently dense to question whether the lidar-derived elevation represented the ground surface or the top of the vegetation mass. At these locations, measured height of massed vegetation averaged 0.5 m, ranging from 0.1 to 1.4 m (app. A). If known, these heights can be subtracted from the lidar-derived elevation profile to produce a corrected ground-surface elevation profile (fig. 19), assuming lidar was unable to penetrate the vegetation at these locations. In densely vegetated areas, vegetation mass heights might cause significant overestimation of land-surface elevation and potential misclassification of environments.

Regardless of the accuracy of the 1992 NWI maps in correctly identifying habitats, transect locations with the highest elevations generally correlated with upland or high palustrine units and locations with the lowest elevations generally coincided with estuarine units (fig. 20). Average elevation was highest (2.6 m) for the 25 locations classified as U (table 2), but elevation for this unit ranged from 0.5 to 5.5 and overlapped with elevation ranges for other mapped units. Unit

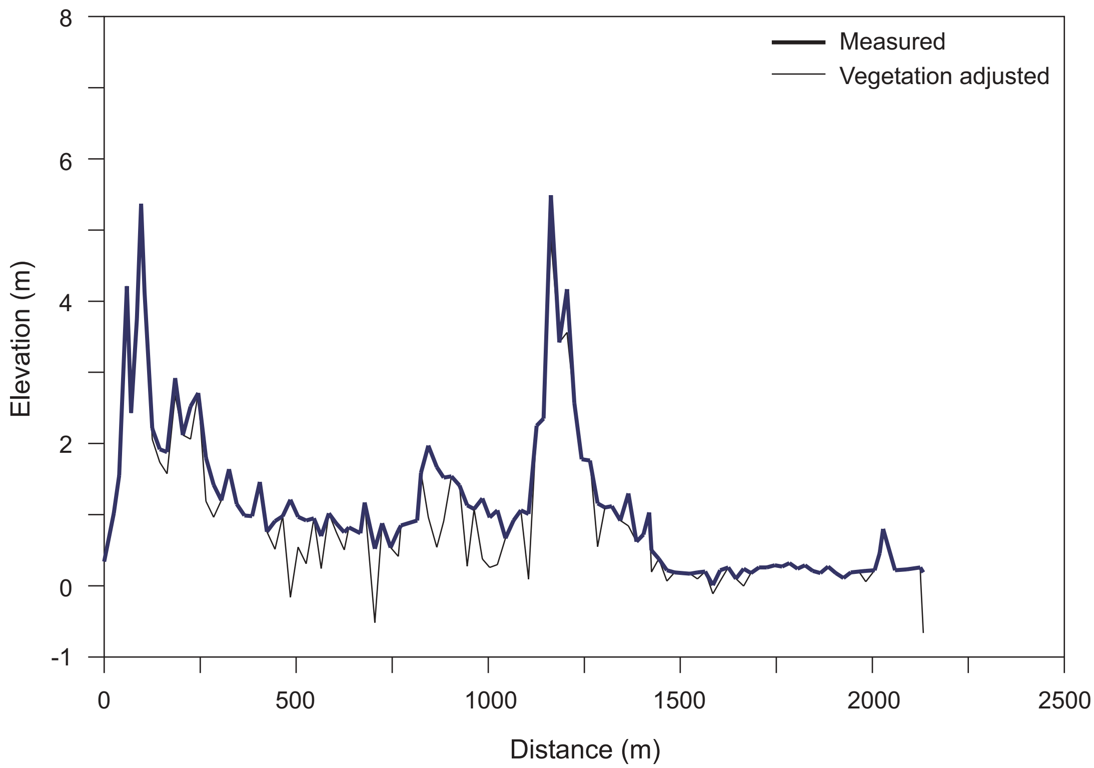

Figure 19. Elevation profiles along the MISP transect. The heavy line represents actual lidar-derived elevations; the lighter line represents the elevation calculated by subtracting the measured height of dense vegetation from the lidar-derived elevation. The gulf shoreline is at the left end of the profile and the bay shoreline is at the right end.

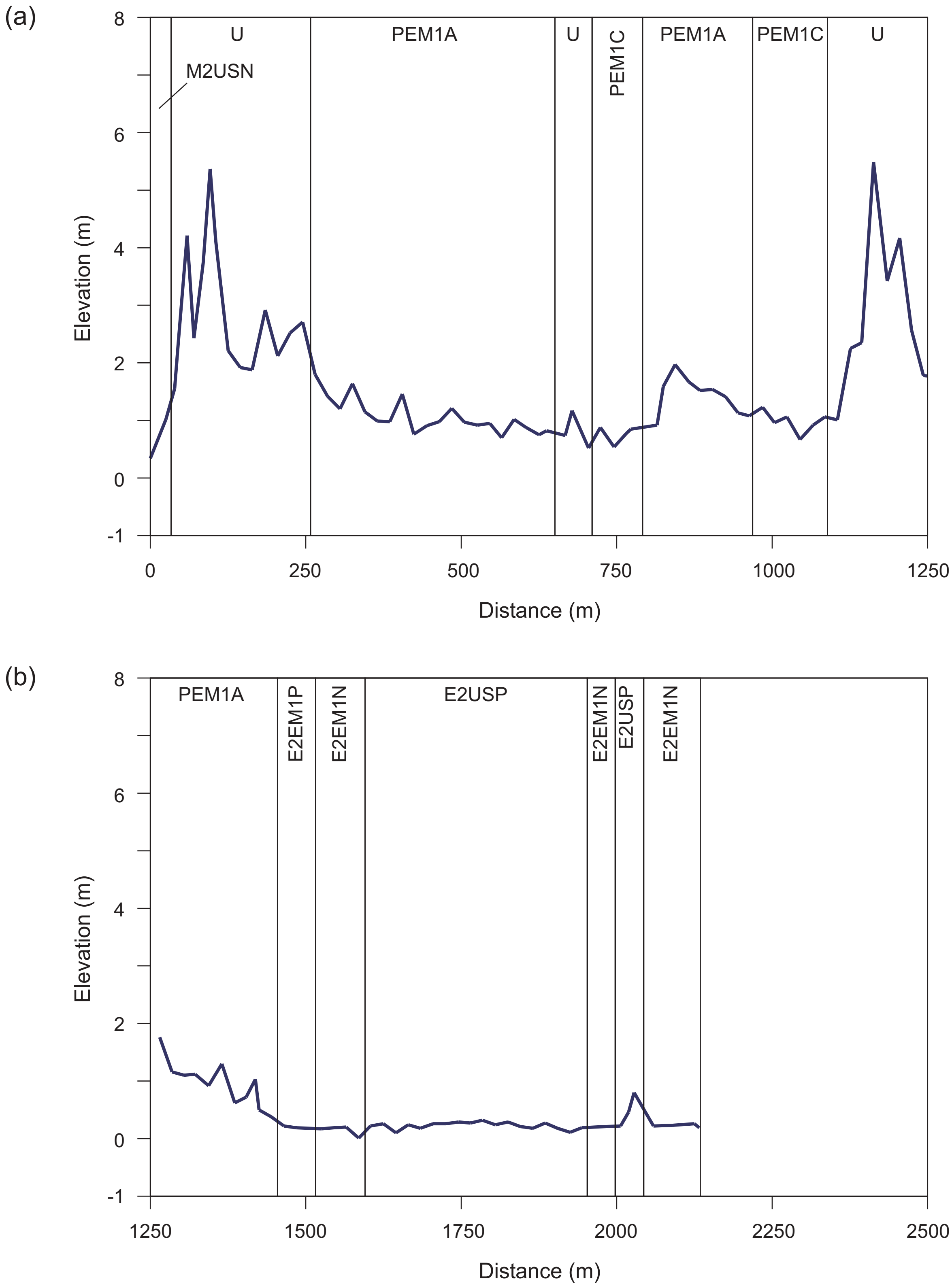

Figure 20. Elevation profile superimposed with 1992 NWI units along the MISP transect (a) between 0 and 1250 m and (b) between 1250 and 2200 m from the Gulf shoreline.

PEM1A, the topographically highest of the mapped palustrine units, had the next highest average elevation (1.1 m). Unit PEM1C, considered topographically lower than PEM1A, had a slightly lower average elevation (0.9 m). Estuarine units E2EM1P, E2EM1N, and E2USP have similar average elevations (0.19 to 0.26 m, table 2) that are considerably lower than those for the upland and palustrine units. Upper and lower elevation limits for the mapped upland and palustrine units overlap, as do ranges for the estuarine units (table 2). There is a distinct difference in average elevation (and little overlap in elevation range) between the palustrine and estuarine units.

During the ground-based survey along the MISP transect, we classified each of the 112 locations into one of nine coastal environments based on vegetation (table 3, fig. 21, app. A). Most common were dune, VBF, and low and high wind-tidal flat, which together account for 85 of the 112 locations. These ground-based surveys produced greater vegetation classification detail than that shown on the NWI maps, as well as one that is more representative of the variability evident from the topographic profile (fig. 21). The dune environment has the highest average elevation (2.6 m) as well as the largest elevation range (0.8 to 5.5 m), overlapping at the low end with the VBF, fresh marsh, and beach environments (table 3). Relatively high elevation averages are associated with VBF (1.3 m), high fresh marsh (0.86 m), low fresh marsh (0.77 m) and beach (0.79 m) environments, which all have some degree of overlap in elevation ranges. Distinctly lower elevation averages are associated with high (0.29 m) and low (0.17 m) salt marsh and high (0.23 m) and low (0.2 m) wind-tidal flat environments. Elevation ranges for these environments overlap with each other, but not with fresh marsh, VBF, or dune environments.

Conductivity and Vegetation Units

Apparent ground conductivities measured along the MISP transect vary over more than three orders of magnitude, ranging from very resistive ground at a few mS/m to relatively conductive ground at more than 2,000 mS/m (table 2 and fig. 22). Conductivities measured at the 112 locations along the transect in the shallow-exploring hd orientation are similar to, but gener-

Table 3. Elevation and apparent conductivity ranges measured at 112 locations for coastal environmental units (fig. 3) along the Mustang Island State Park transect (app. A). Elevations were measured using an airborne lidar instrument. Apparent conductivities were measured using a ground-based Geonics EM38 instrument in the vertical dipole (vd) and horizontal dipole (hd) orientations. VBF = vegetated barrier flat, MFH = high fresh marsh, MFL = low fresh marsh, MSH = high salt marsh, MSL = low salt marsh, WTFH = high wind-tidal flat, WTFL = low wind tidal flat.

Environment	n	Elev. avg. (m)	Elev. range (m)	App. con. avg., vd (mS/m)	App. con. range, vd (mS/m)	App. con. avg., hd (mS/m)	App. con. range, hd (mS/m)
Dune	21	2.64	0.8-5.49	59	2-767	38	1-505
VBF	37	1.31	0.5-2.92	76	4-561	57	2-514
MFH	4	0.86	0.7-1.06	145	42-329	99	34-221
MFL	9	0.77	0.52-1.06	242	43-408	202	30-270
MF (all)	13	0.8	0.52-1.06	212	42-408	170	30-270
MSH	3	0.29	0.22-0.38	1175	852-1392	1150	842-1445
MSL	4	0.17	0.01-0.25	1223	1106-1345	1263	1119-1429
MS (all)	7	0.22	0.01-0.38	1202	852-1392	1214	842-1445
WTFH	20	0.23	0.1-0.46	1489	1157-1783	1565	1046-2021
WTFL	7	0.2	0.17-0.23	1397	1279-1592	1477	1224-1715
WTF (all)	27	0.22	0.1-0.46	1465	1157-1783	1542	1046-2021
Beach, berm	4	0.79	0.26-1.55	578	91-1192	604	72-1219
Water	2	0.78	0.74-0.82	33	25-40	29	27-31

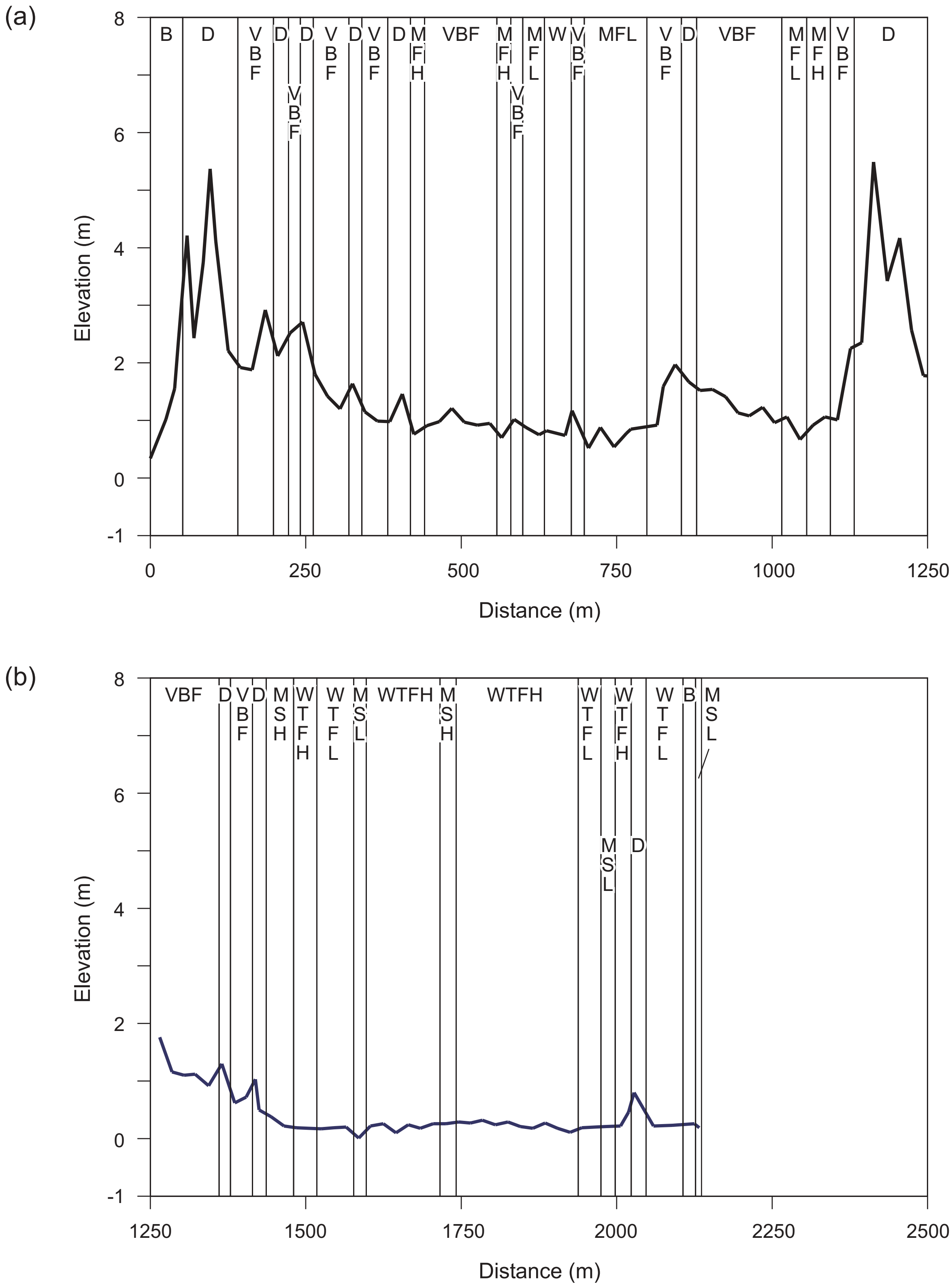

Figure 21. Elevation profile superimposed with surveyed coastal environments along the MISP transect (a) between 0 and 1250 m and (b) between 1250 and 2200 m from the gulf shoreline.

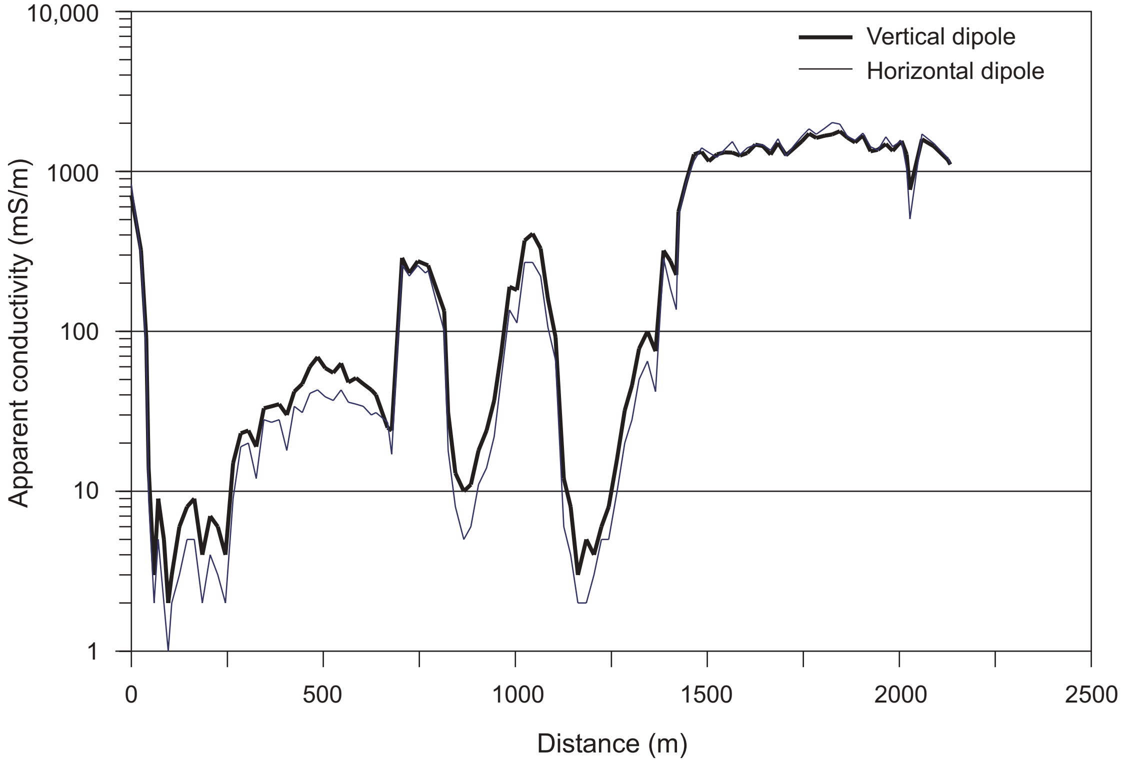

Figure 22. Apparent ground conductivity measured along the MISP transect using the Geonics EM38 in the vertical dipole (heavy line) and horizontal dipole (light line) orientation.

ally lower than, conductivities measured in the deeper-exploring vd orientation. Highest apparent conductivities (greater than 100 mS/m) were measured within a few tens of meters of the gulf shoreline, along two mid-island segments about 750 and 1000 m from the gulf shoreline, and along a long segment from the bay shoreline to a point about 700 m inland (fig. 22). Lowest apparent conductivities (about 10 mS/m or less) were measured between 50 and 250 m inland from the gulf shoreline and along two mid-island segments about 850 and 1200 m inland from the gulf shoreline.

Measured apparent conductivities correlate reasonably well spatially with mapped NWI units (fig. 23 and table 2). Upland (U) and high palustrine (PEM1A) units tend to occur where apparent conductivities are low (less than about 100 mS/m), whereas lower palustrine (PEM1C), estuarine (E2EM1P, E2EM1N, and E2USP), and marine (M2USN) units have been mapped where apparent conductivities are relatively high (greater than 100 mS/m). Among the more conductive NWI units, average apparent conductivities measured in the vd mode (table 2) are highest for the topographically lowest estuarine unit (1467 mS/m for E2USP), decrease slightly for the next lowest estuarine unit (1318 mS/m for E2EM1N), and decrease again for the highest of the mapped estuarine units (1254 mS/m for E2EM1P). There is considerable overlap in measured apparent conductivities for these units. The marine-influenced unit (M2USN) averaged 515 mS/m, followed by the lowest palustrine unit (PEM1C) at 266 mS/m. There is no overlap between conductivities measured for these units and those measured for the more conductive estuarine units (table 2). Among the relatively nonconductive NWI units, the lowest average conductivity (26 mS/m) is associated with locations within areas mapped as upland (U). Slightly higher average conductivity (94 mS/m) is associated with the highest palustrine unit (PEM1A). The conductivity range measured for locations within U units overlapped with ranges measured for locations within palustrine units, but not with marine or estuarine units.

Coastal environments surveyed along the MISP transect also correlate well with measured apparent conductivity (table 3 and fig. 24). Highest apparent conductivities measured in the vd orientation occur in beach, low fresh marsh, low and high salt marsh, and low and high wind-

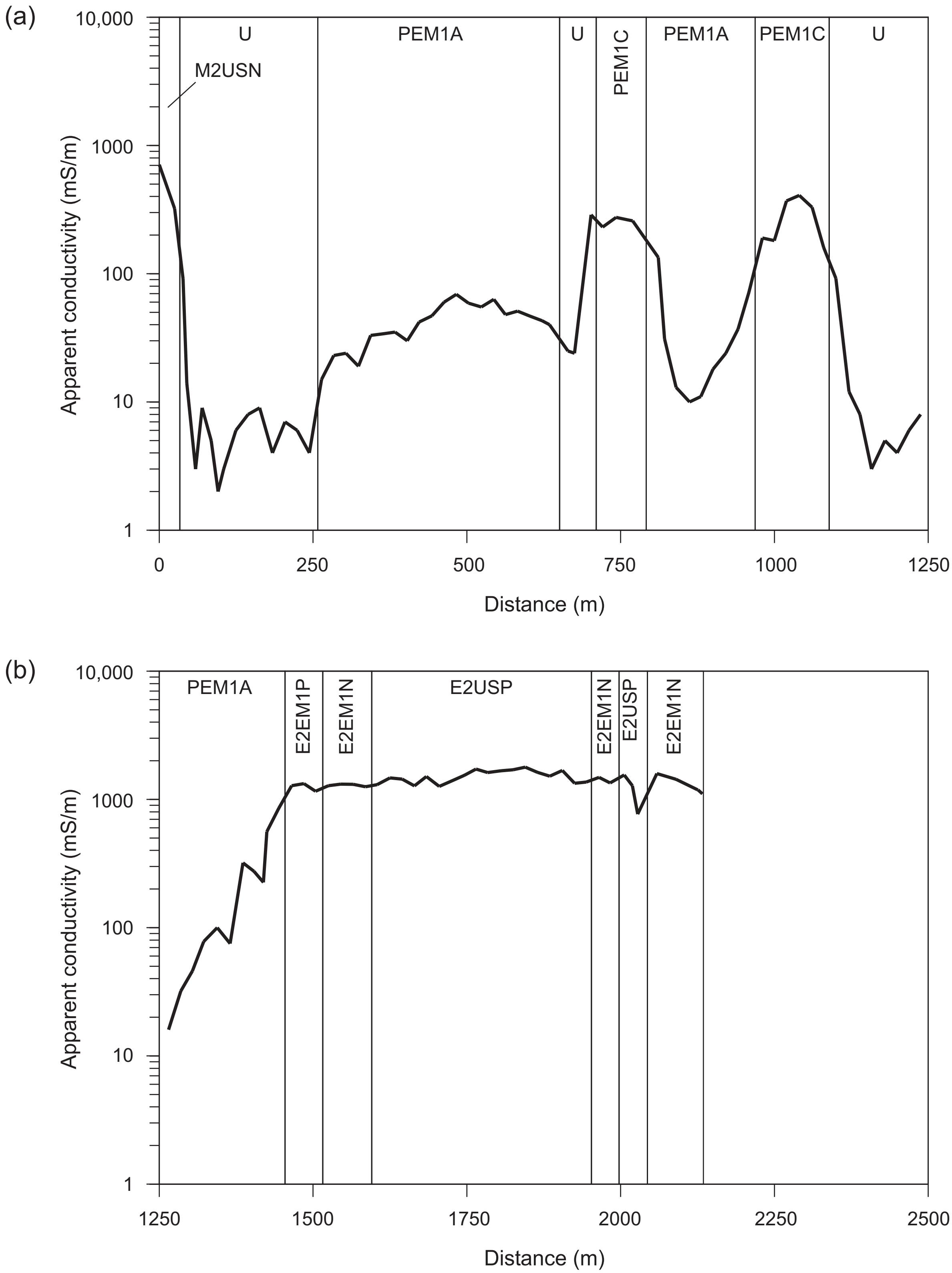

Figure 23. Apparent conductivity profile (vertical dipole orientation) superimposed with 1992 NWI units along the MISP transect (a) between 0 and 1250 m and (b) between 1250 and 2200 m from the gulf shoreline.

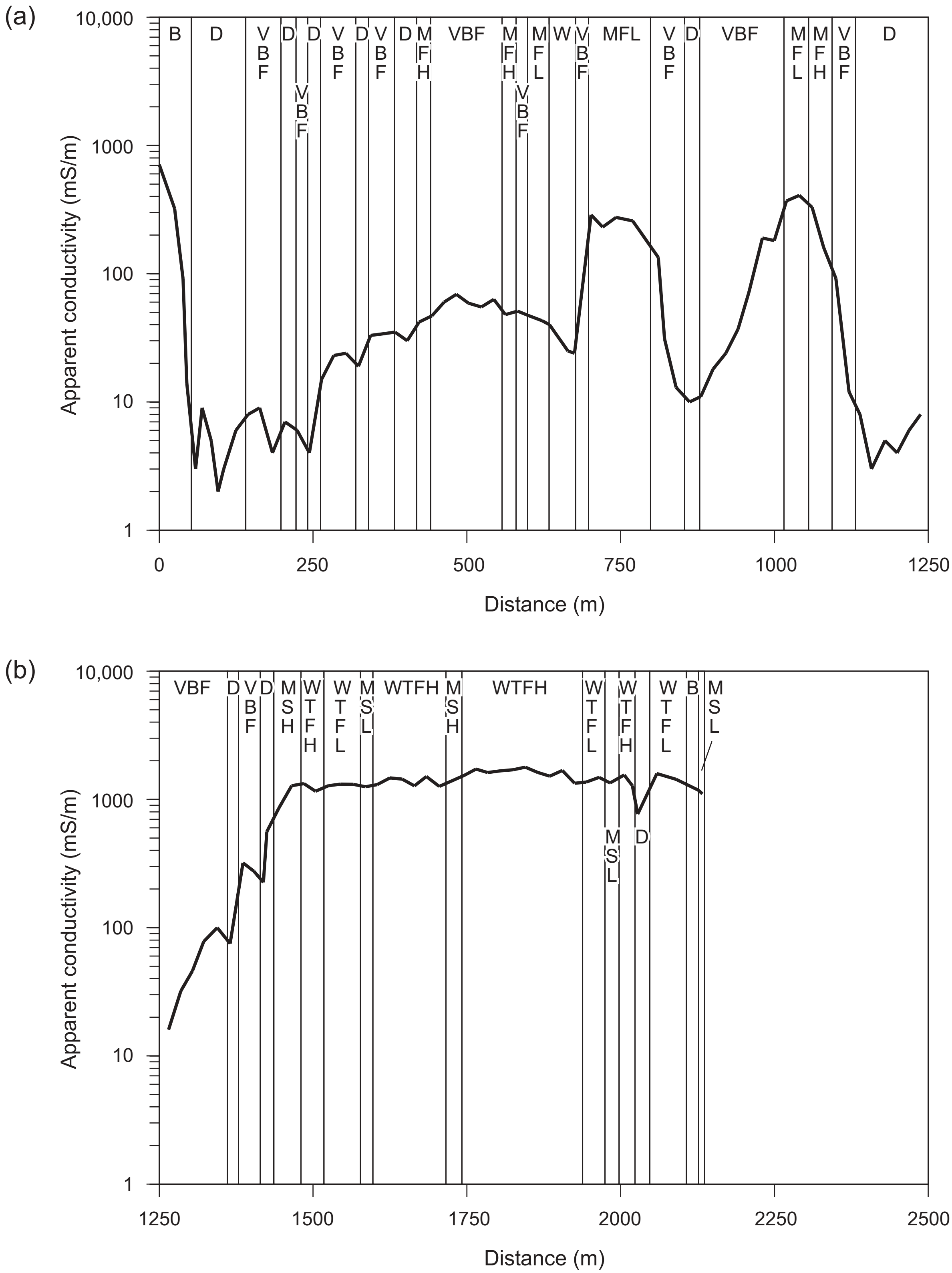

Figure 24. Apparent conductivity profile (vertical dipole orientation) superimposed with surveyed coastal environments along the MISP transect (a) between 0 and 1250 m and (b) between 1250 and 2200 m from the gulf shoreline.

tidal flat environments (fig. 24). Lowest apparent conductivities occur in dune, VBF, and low and high fresh marsh environments (fig. 24). Locations within dune environments have the lowest average conductivity (59 mS/m, vd orientation), but their measured range extends above the average values observed for low (242 mS/m) and high (145 mS/m) fresh marshes (table 3). Low average conductivities (76 mS/m, vd orientation) are also found in VBF environments. Gulf beach and bay berm environments have higher average apparent conductivities (578 mS/m) than are found in dune and fresh marsh environments. Salt marsh and wind-tidal flats have the highest apparent conductivities; each environment averages more than 1000 mS/m (vd orientation). There is an increase in average apparent conductivity from high (1175 mS/m, vd orientation) to low (1223 mS/m) salt marsh and from low (1397 mS/m) to high wind-tidal flat (1489 mS/m). Ranges of measured conductivities overlap for the salt marsh and wind-tidal flats and for the dunes, VBFs, and fresh marshes, but there is little or no overlap in observed conductivity range between these two groups of relatively saline and non-saline environments.

Elevation, Conductivity, and Vegetation Units

In general, elevation and apparent conductivity vary inversely along the MISP profile (fig. 25), reflecting the strong inverse correlation between elevation and salinity in coastal environments. As elevation decreases, the frequency of flooding by saline water increases. At higher elevations, infrequent saline flooding, infiltrating fresh precipitation, and relatively dry soil combine to produce less electrically conductive soil. Conductivity values show a greater range of variation than do elevations, but both types of data vary significantly across the island.

By combining elevation and apparent conductivity, we can attempt to better discriminate NWI and coastal environment units that may have overlapping elevation or conductivity ranges (fig. 26). For example, locations within the upland (U) NWI unit generally have both low apparent conductivities and high elevations, whereas the highest palustrine unit (PEM1A) generally has lower elevations and higher conductivities (fig. 26a). High and low palustrine units PEM1A

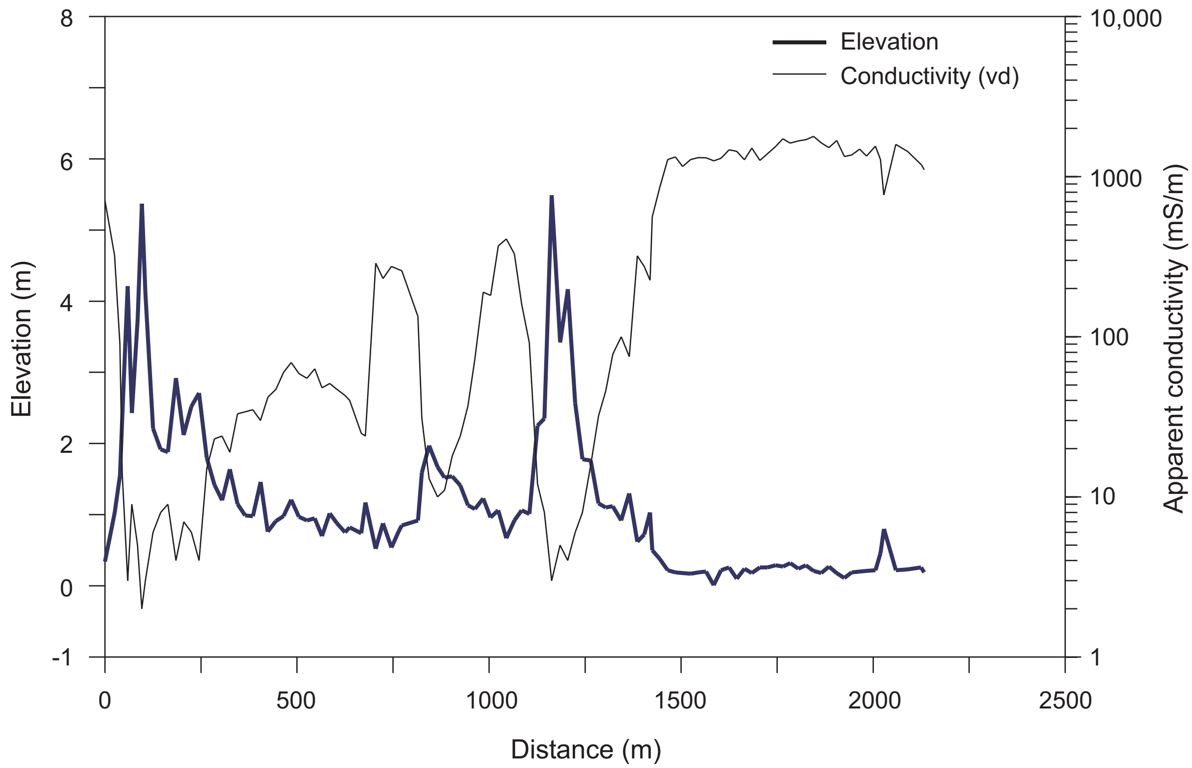

Figure 25. Elevation (heavy line) and apparent conductivity (light line) profiles along the MISP transect.

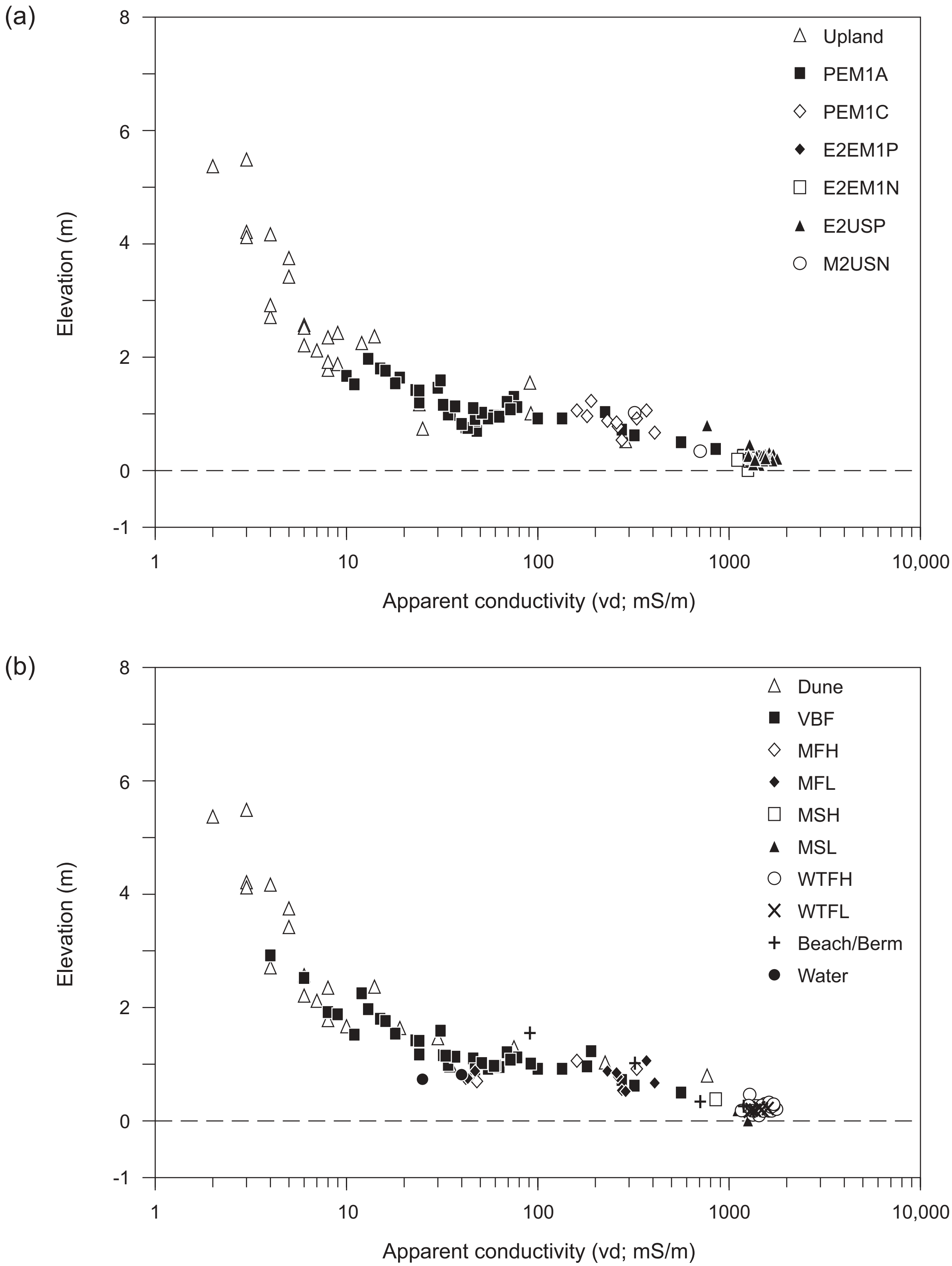

Figure 26. Elevation and apparent conductivity of (a) 1992 NWI units, and (b) coastal environments along the MISP transect. Apparent conductivity measured in the vd orientation.

and PEM1C have minor differences in elevation but more distinct differences in apparent conductivity. All estuarine and marine units have both very low elevations and very high apparent conductivities.

Similarly, dune environments have high and highly variable elevations, but have low conductivities that vary over a relatively small range (fig. 26b). VBF environments generally have lower elevations than dune environments and higher and more variable conductivity values. High fresh marshes have elevations that are indistinguishable from VBF environments, but have apparent conductivities that tend to be higher than those observed in VBF environments. Salt marsh and wind-tidal flat environments all have very low elevations and very high apparent conductivities.

PORT ARANSAS TRANSECT

The Port Aransas (PA) transect is located on the northeast part of Mustang Island (figs. 2 and 27). This transect extends 2.4 km from the gulf beach to the modified and frequently flooded wetlands several hundred meters inland from Corpus Christi Bay. We surveyed vegetation and measured apparent conductivity at 122 locations along this transect (app. B and C) and obtained elevations at these locations from a DEM (fig. 28) constructed from lidar data acquired in 2003 along a swath about 350 m wide that was centered on the transect.

Wetland Units and Coastal Environments

We used a geographic information system to extract transect locations that are within units mapped on the 1992 NWI (tables 1 and 4) to compare vegetation, elevation, and conductivity data with existing habitat data. In contrast with the relatively undisturbed MISP transect, segments of the PA transect have been altered by human activities such as residential development, sewage disposal, channel dredging and modification, and dredge material disposal. More than half (66 of 122) of the locations on the PA transect are classified in the 1992 NWI as estuarine

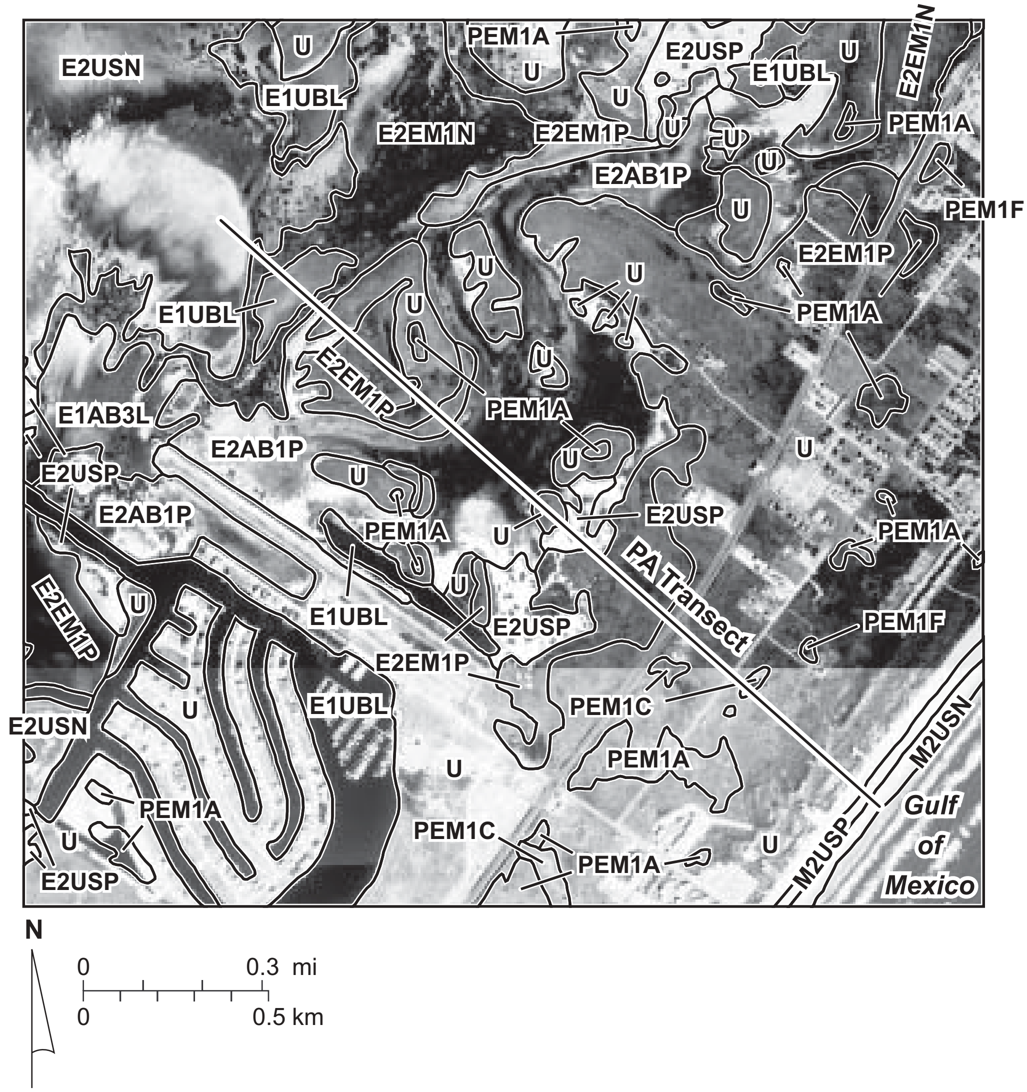

Figure 27. Aerial photomosaic of the PA transect showing habitats identified on the 1992 NWI maps. The photomosaic was compiled from aerial photographs flown in 1995 and obtained from the Texas Natural Resource Information System (TNRIS).

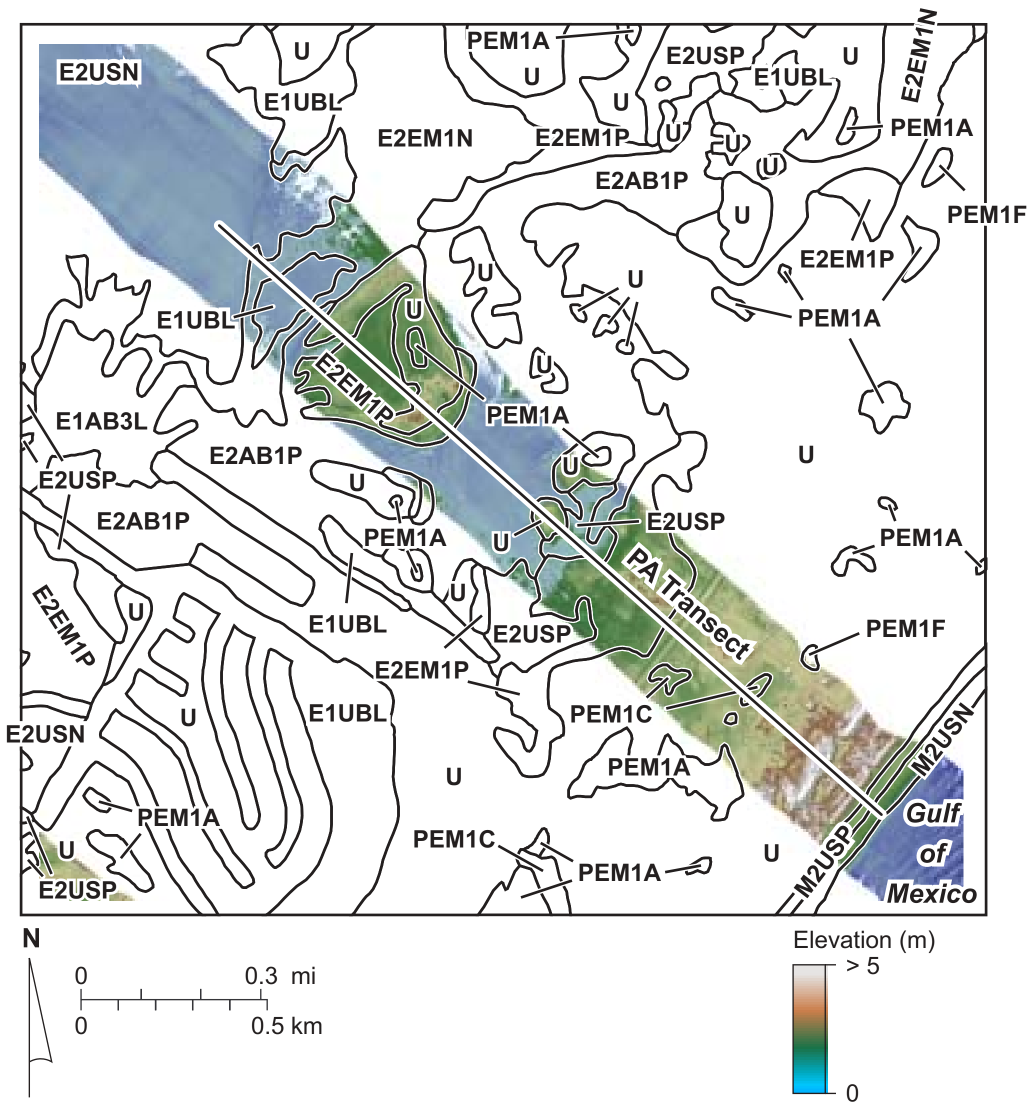

Figure 28. Digital elevation model (DEM) of the PA transect showing habitats identified on the 1992 NWI maps. The DEM was constructed from lidar data acquired along the transect in 2003.

Table 4. Elevation and apparent conductivity ranges measured at 122 locations for 1992 NWI units mapped along the Port Aransas transect (app. B). Elevations were measured using an airborne lidar instrument. Apparent conductivities were measured using a ground-based Geonics EM38 instrument in the vertical dipole (vd) and horizontal dipole (hd) orientations.

NWI unit	n	Elev. avg. (m)	Elev. range (m)	App. con. avg., vd (mS/m)	App. con. range, vd (mS/m)	App. con. avg., hd (mS/m)	App. con. Range, hd (mS/m)
U	51	2.08	0.42-7.47	78	1-707	65	2-956
PEM1C	1,2	1.28		117	97-137	104	78-129
E2EM1P	30	0.89	0.2-1.72	488	17-1571	449	10-1767
E2EM1N	8	0.16	0.09-0.32	1272	1113-1464	1382	1139-1469
E2USP	5	0.33	0.16-0.73	1274	527-1800	1281	331-2029
E2USN	6	0.07	0.03-0.09	1863	1652-1950	2049	1747-2251
E2AB1P	16	0	-0.11-0.09	1660	1245-1828	1892	1301-2211
E1UBL	1	0.1		985		1041	
M2USP	1	0.87		269		276	
M2USN	2	0.63	0.5-0.75	581	428-733	614	444-784

(E1UBL, E2AB1P, E2USN, E2USP, E2EM1N, or E2EM1P); slightly less than half (51) are classified as upland (U, table 4). The remaining few locations are mapped either as marine (M2USN or M2USP at three locations near the gulf shoreline) or palustrine (PEM1C at two locations bayward of the dunes).

Because NWI maps are largely based on aerial photographic interpretation, extents of units depicted on the NWI maps correspond reasonably well to tonal boundaries on the aerial photograph of the PA transect area (fig. 27). Elevation changes depicted on the detailed digital elevation model constructed from the lidar data also correlate well with NWI boundaries, but there are significant elevation changes in areas where a single NWI unit is mapped (fig. 28). Habitat boundaries are commonly clearly expressed and readily mapped on aerial photographs, but the habitat type may be difficult to distinguish from aerial photographic expression alone.

Field observations allow greater detail and accuracy in establishing the appropriate coastal environment for a given location. As was also true for the MISP transect, comparing mapped NWI habitats and field-determined coastal environments (fig. 29) shows that NWI units commonly include several coastal environments. For example, ground-based observations reveal that 32 out of 51 locations mapped within the 1992 NWI upland unit (U) are classified as VBF and 14 locations are classified as dune environments, both of which are common in uplands. The interpreted coastal environments at the remaining 5 transect locations within the upland unit are beach, low and high fresh marsh, and high salt marsh. At a more detailed mapping scale, these environments would not be classified as upland. The second-most common NWI unit along the PA transect is the irregularly flooded estuarine intertidal wetland (E2EM1P). The most common coastal environment observed within this mapped unit is VBF (17 out of 30 locations), which is generally considered to be an upland environment. Other environments interpreted within the 1992 E2EM1P habitat on the PA transect are high salt marsh (10 locations) and wind-tidal flat (3 locations).

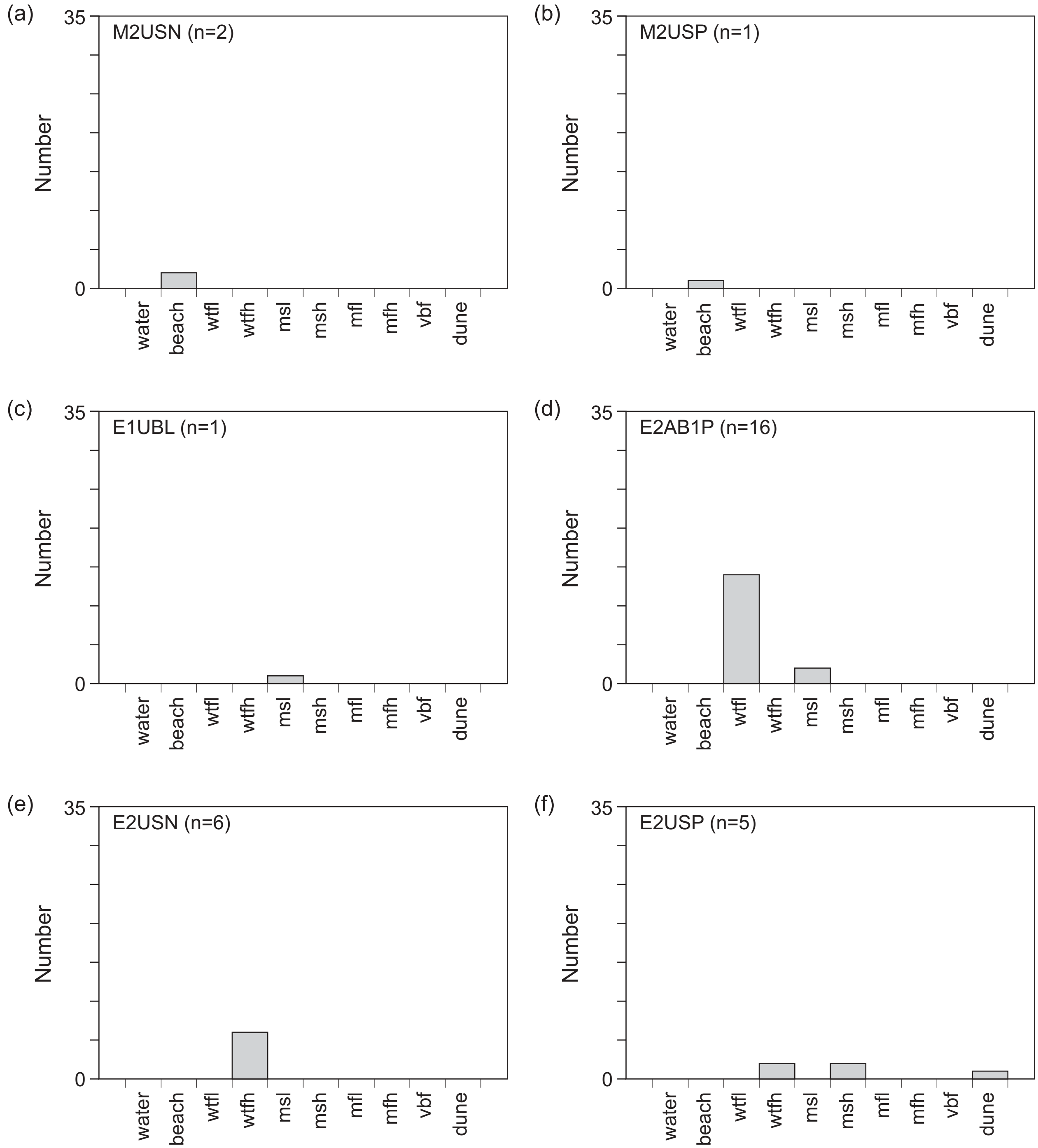

Figure 29. Distribution of coastal environments identified along the PA transect for each 1992 NWI unit.

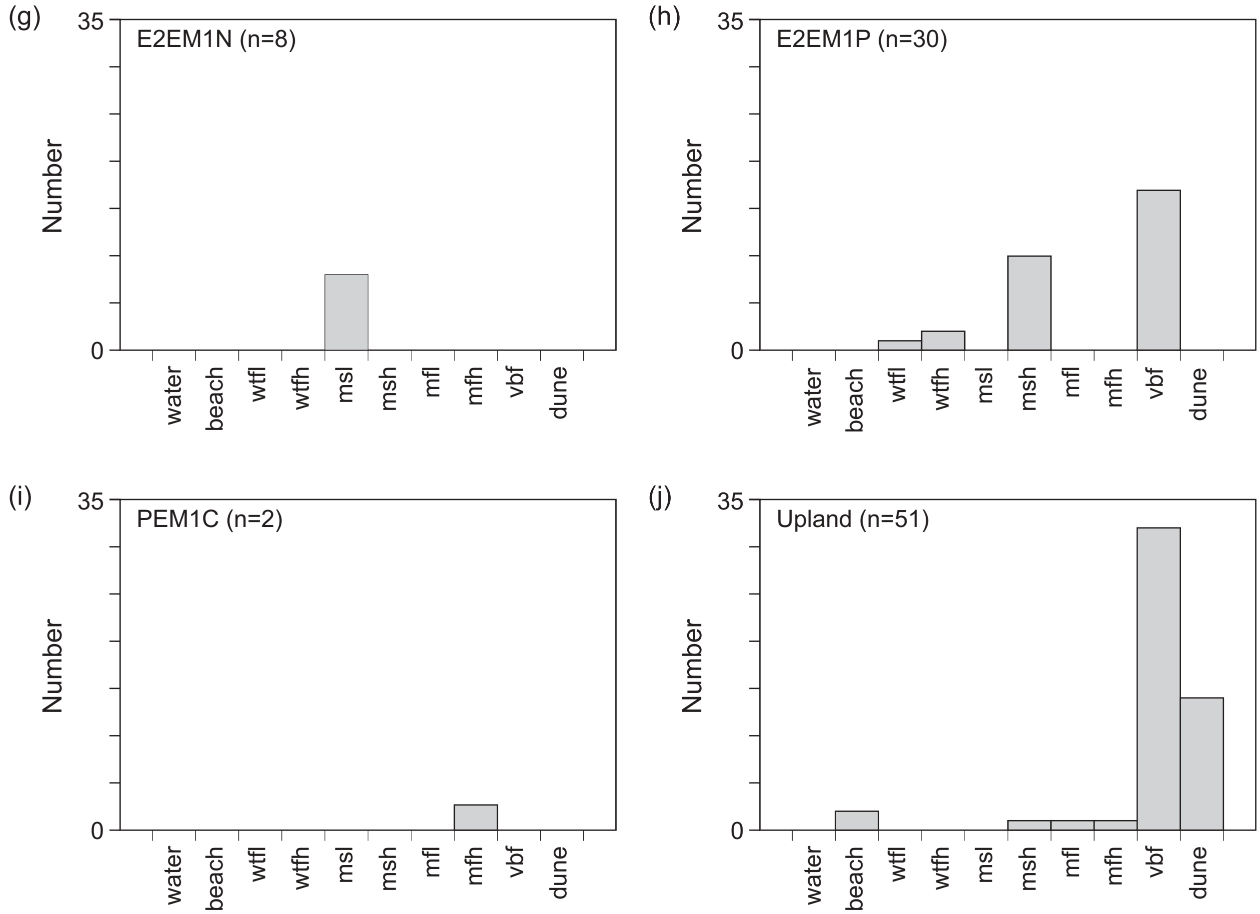

Figure 29 (continued).

Elevation and Vegetation Units

Lidar-derived elevations at the 122 locations along the PA transect range from -0.1 to 7.5 m NAVD (figs. 28 and 30, app. B). Highest elevations (2 m or more) were measured across the fore-island dunes within about 300 m of the gulf shoreline. Elevations within about 1000 m of the gulf shoreline are generally above 1 m. Farther bayward, elevations are below 1 m except along short segments where elevation exceeds 1 m at distances of about 1.2, 1.7, and 2 km from the gulf shoreline.

The height of massed vegetation represents potential land-surface elevation error if the lidar pulse does not penetrate the dense vegetation. Measured height of dense vegetation averaged 0.5 m, ranging from 0.1 to 1 m at 72 locations along the PA transect (app. B). If we assume that the lidar-derived elevation represents the top of dense vegetation at these sites, we can subtract the vegetation height to produce a corrected land-surface elevation (fig. 30). The largest corrections occur at high elevations (upland, dune, and VBF habitats) where plant stature and density is commonly greater than in lower environments.

The PA transect elevation profile (uncorrected for vegetation height) correlates reasonably well with 1992 NWI units (fig. 31). Highest elevations on the profile coincide with areas mapped as upland (U). Marine NWI units are found at low elevations at the gulf shoreline. Locations with the lowest elevations are within an area mapped as irregularly flooded estuarine intertidal aquatic bed (E2AB1P) at a mid-island topographic low between about 1.3 and 1.5 m from the gulf shore (fig. 31b).

Locations within the upland unit (U) have the highest average elevation (2.1 m) of all NWI units mapped along the PA transect (table 4). These 51 locations range widely from 0.4 to 7.5 m in elevation, a range that overlaps at the low end with several palustrine, estuarine, and marine wetland units (table 4). Next highest is the seasonally flooded palustrine unit (PEM1C) at 1.3 m, followed by the irregularly flooded estuarine unit E2EM1P and irregularly flooded marine unit M2USP at about 0.9 m and the regularly flooded marine unit M2USN at 0.6 m. Average eleva-

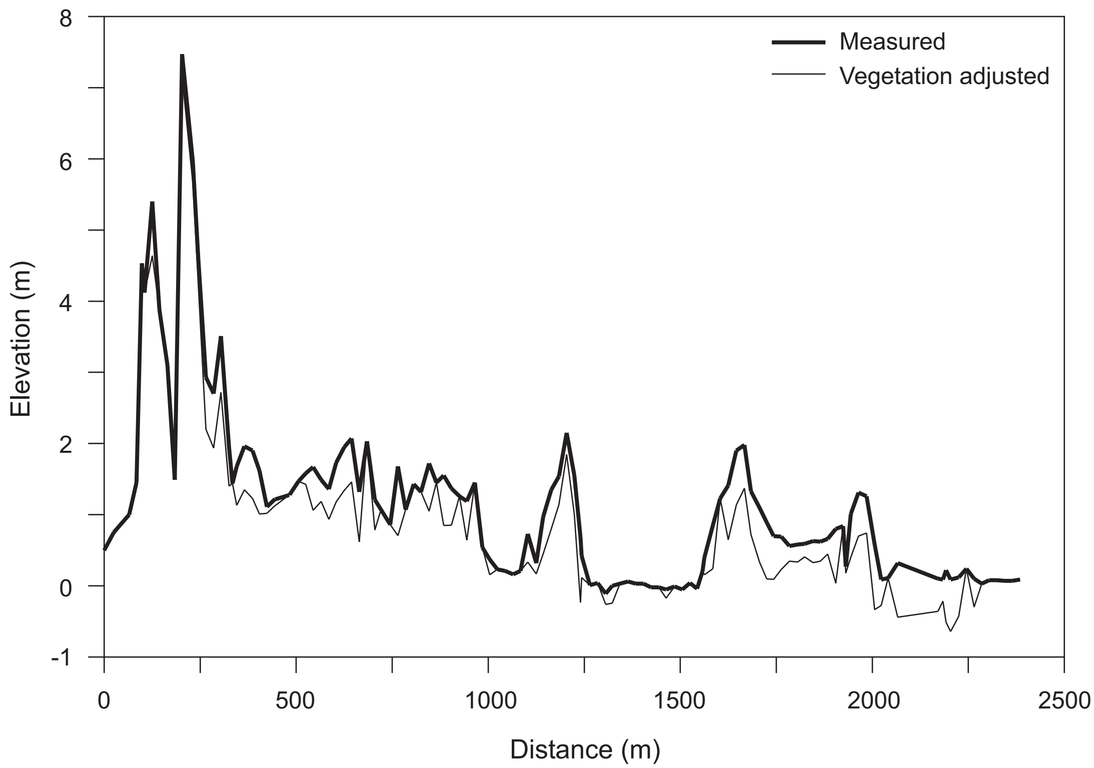

Figure 30. Elevation profiles along the PA transect. The heavy line represents actual lidar-derived elevations; the lighter line represents the elevation calculated by subtracting the measured height of dense vegetation from the lidar-derived elevation. The gulf shoreline is at the left end of the profile.

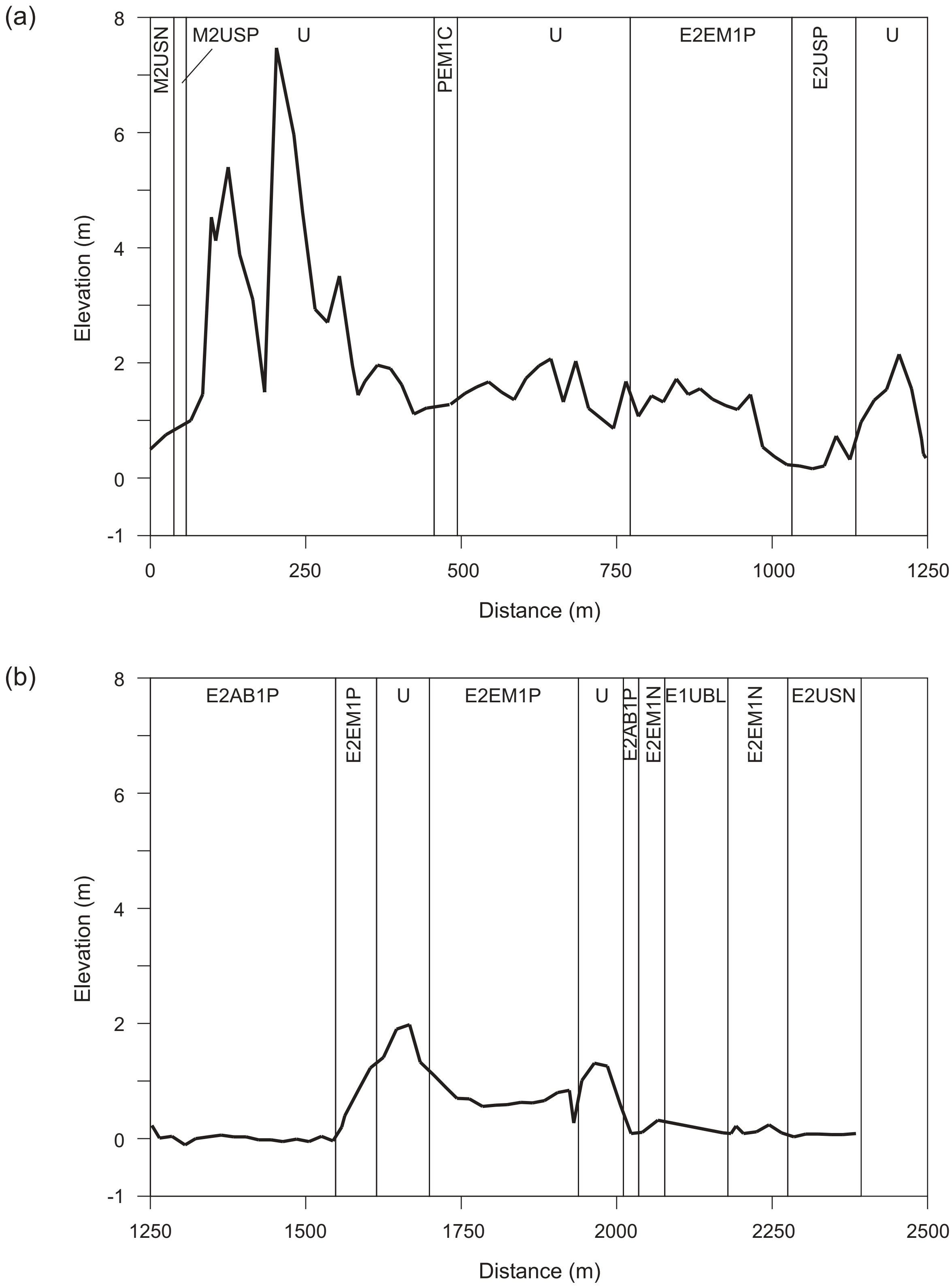

Figure 31. Elevation profile superimposed with 1992 NWI units along the PA transect (a) between 0 and 1250 m and (b) between 1250 and 2400 m from the gulf shoreline.

tions for the remaining estuarine units are 0.3 m or lower. Among locations within similar NWI units (E2USP and E2USN, for example), increasing flooding frequency correlates with decreasing average elevation (table 4).

Coastal environments along the PA transect identified during the field investigation have a level of detail that is greater than that shown on NWI maps (fig. 31) and more closely matches topographic detail obtained from lidar (fig. 32). A strong spatial correlation between elevation and coastal environment is evident. Dunes and VBFs are found where elevations are relatively high, VBFs and fresh marshes occur at intermediate elevations, and salt marshes and wind-tidal flats occupy the lowest island elevations (fig. 32). Average elevation at locations classified as dune is 3.0 m, the highest of all coastal environments along the transect (table 5). Elevation for the one low fresh marsh location is 2.0 m, significantly higher than the 1.1 m average elevation of the three high fresh marsh locations. Measured vegetation heights of about 2 m at the low fresh marsh location suggest that the lidar elevation does not represent the ground surface. Average elevation at high salt marsh locations is 0.5 m, distinctly higher than the low salt marsh average of 0.1 m and the wind-tidal flat averages of 0.1 m for high and 0.0 m for low wind-tidal flats. Elevation ranges overlap significantly for the low salt marsh and wind-tidal flat environments. High salt marshes have a distinct elevation range with little overlap with higher or lower environments. Fresh-marsh elevations can overlap with elevations measured for VBF and dune environments.

Conductivity and Vegetation Units

Apparent ground conductivities measured along the PA transect vary over more than three orders of magnitude, from nonconductive values near 1 mS/m to relatively conductive values of more than 2,000 mS/m (fig. 33). Values measured in the shallower-exploring horizontal dipole orientation are very similar to values measured in the deeper-exploring vertical dipole orientation, but are slightly lower at most locations. Highest apparent conductivities were measured

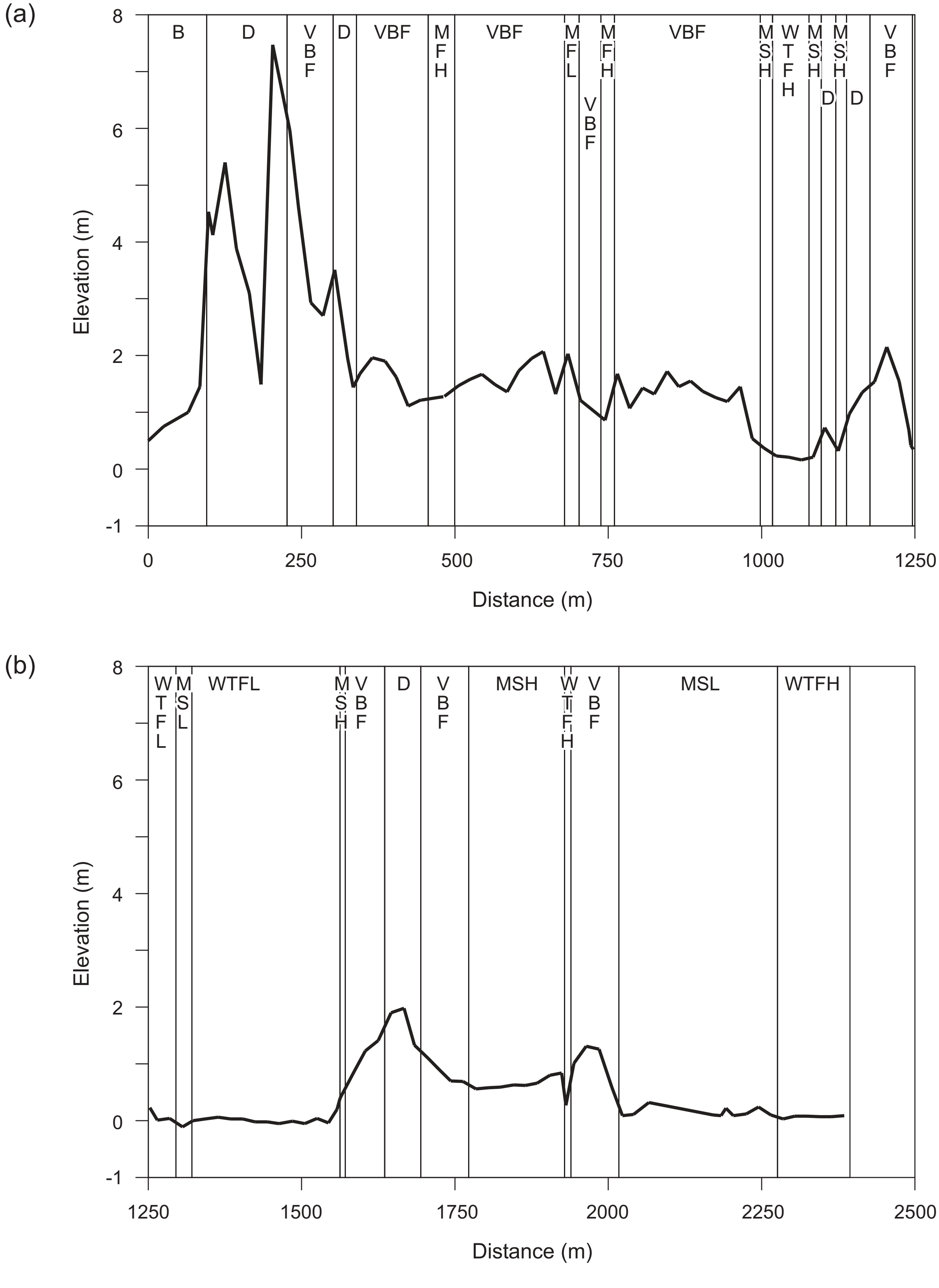

Figure 32. Elevation profile superimposed with surveyed coastal environments along the PA transect (a) between 0 and 1250 m and (b) between 1250 and 2400 m from the gulf shoreline.

Table 5. Elevation and apparent conductivity ranges measured at 122 locations for coastal environmental units (fig. 3) along the Port Aransas transect (app. B). Elevations were measured using an airborne lidar instrument. Apparent conductivities were measured using a ground-based Geonics EM38 instrument in the vertical dipole (vd) and horizontal dipole (hd) orientations. VBF = vegetated barrier flat, MFH = high fresh marsh, MFL = low fresh marsh, MSH = high salt marsh, MSL = low salt marsh, WTFH = high wind-tidal flat, WTFL = low wind tidal flat.

Environment	n	Elev. avg. (m)	Elev. range (m)	App. con. avg., vd (mS/m)	App. con. range, vd (mS/m)	App. con. avg., hd (mS/m)	App. con. range, hd (mS/m)
Dune	13	3.01	0.73-7.47	93	1-527	60	2-331
VBF	49	1.57	0.54-5.96	114	1-812	93	2-731
MFH	3	1.07	0.86-1.28	94	49-137	83	42-129
MFL	1	2.03		50		41	
MF (all)	4	1.39	0.86-2.03	83	49-137	73	41-129
MSH	13	0.54	0.21-0.84	797	449-1222	726	288-1138
MSL	11	0.12	-0.11-0.32	1285	985-1732	1394	1041-1937
MS (all)	24	0.35	-0.11-0.84	1021	449-1732	1032	288-1937
WTFH	10	0.13	0.03-0.27	1762	1396-1950	1937	1485-2251
WTFL	15	0.02	-0.05-0.2	1643	1055-1828	1871	1035-2211
WTF (all)	25	0.06	-0.05-0.27	1691	1055-1950	1897	1035-2251
Beach, berm	5	0.91	0.5-1.45	320	33-733	336	26-784

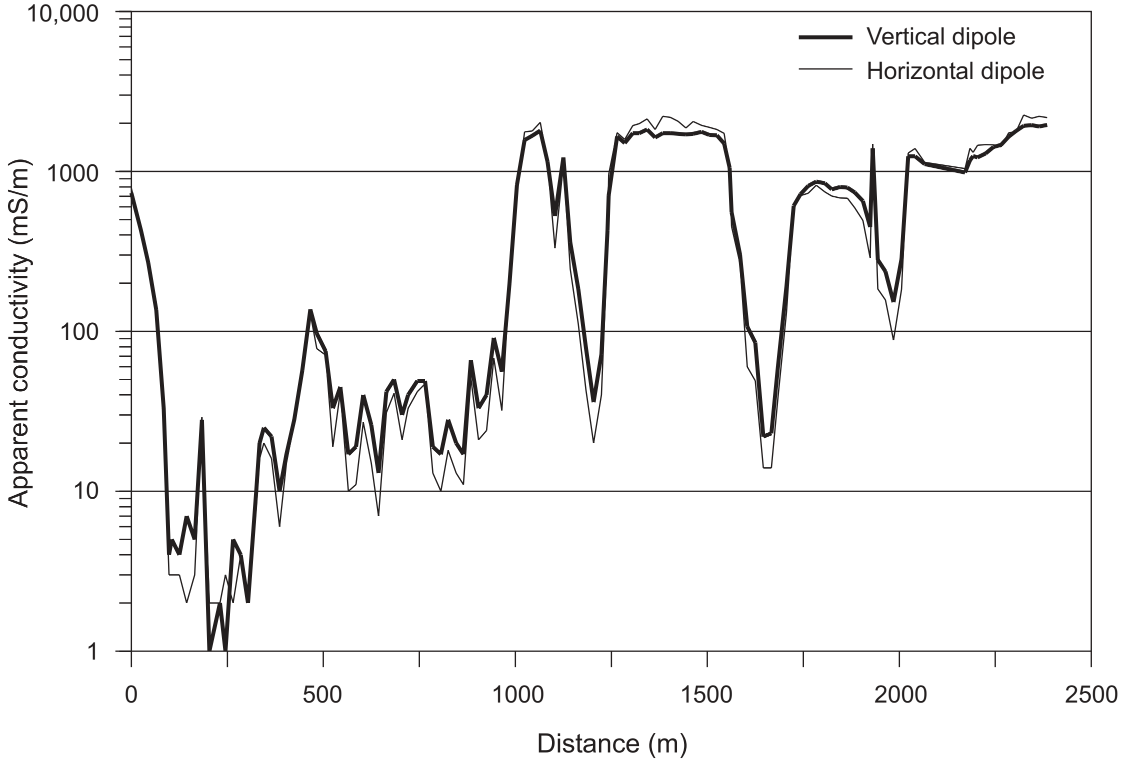

Figure 33. Apparent ground conductivity measured along the PA transect using the Geonics EM38 in the vertical dipole (heavy line) and horizontal dipole (light line) orientation.

within 100 m of the gulf shoreline and along a broad zone extending 1.4 km toward the gulf from the bayward end of the transect. Relatively low conductivities (about 100 mS/m or less) were measured between 100 and 1000 m from the gulf shore and along three short segments at about 1.2, 1.7, and 2 km inland from the gulf shoreline.

With a notable exception, general trends on the conductivity profile along the PA transect correlate reasonably well with 1992 NWI units (fig. 34). At several locations, small-scale NWI map units encompass zones having systematic variations in apparent conductivity that suggest more than one habitat type may be present. Lowest conductivities (200 mS/m or less) are measured within the mapped upland (U) unit; elevated conductivities coincide with higher salinity estuarine and marine NWI units. A small palustrine unit about 500 m from the gulf shoreline coincides with measured conductivities higher than those at locations within the adjacent upland unit. Between about 800 and 1000 m from the gulf shoreline, however, the mapped estuarine unit E2EM1P contains transect locations with relatively low conductivities that would better match those of upland units. The elevations (1 to 2 m, fig. 32a) and coastal environment (VBF, fig. 35a) identified along this stretch suggest that this segment should be mapped as an upland rather than an estuarine unit.

The greater resolution of field-based coastal environment classification more closely matches the lateral resolution achievable with ground-based conductivity measurements (fig. 35). Further, there are few if any discrepancies between identified coastal environment and measured conductivity. Elevated conductivities coincide with beach, wind-tidal flat, and salt marsh environments; low conductivities coincide with dune, VBF, and fresh marsh environments. Lowest conductivities are measured at transect locations on high fore-island dunes and elevated VBF environments. Less well-developed dunes at lower elevations have conductivities that approach, but are lower than, those of surrounding salt marshes and wind-tidal flats.

Statistically, conductivities measured for the saline environments (salt marsh, wind-tidal flat, and forebeach) are very high and distinctly higher than those measured for dune, VBF, and fresh marsh environments (table 5). Highest average conductivities were measured on wind-tidal

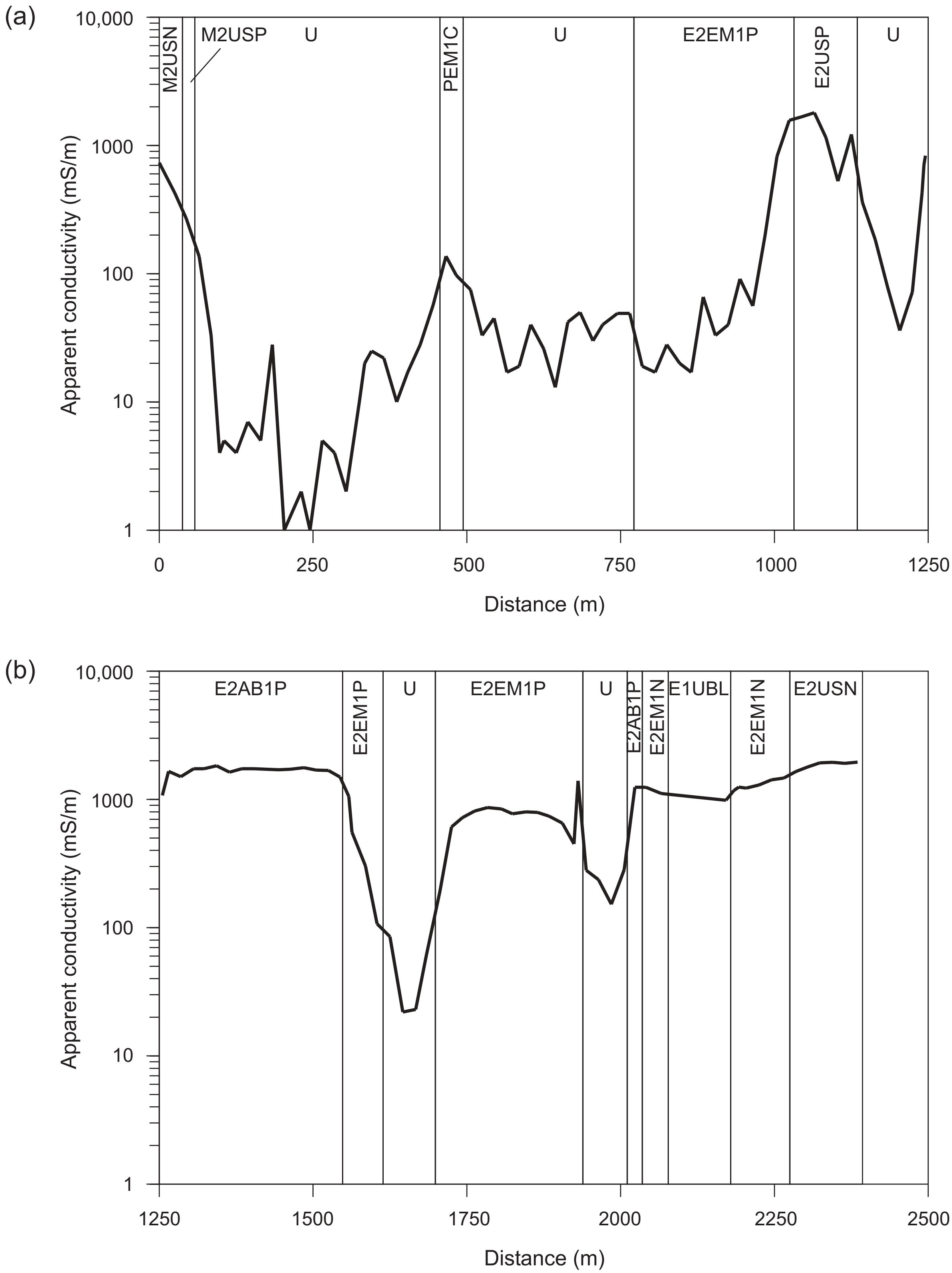

Figure 34. Apparent conductivity profile (vertical dipole orientation) superimposed with 1992 NWI units along the PA transect (a) between 0 and 1250 m and (b) between 1250 and 2400 m from the gulf shoreline.

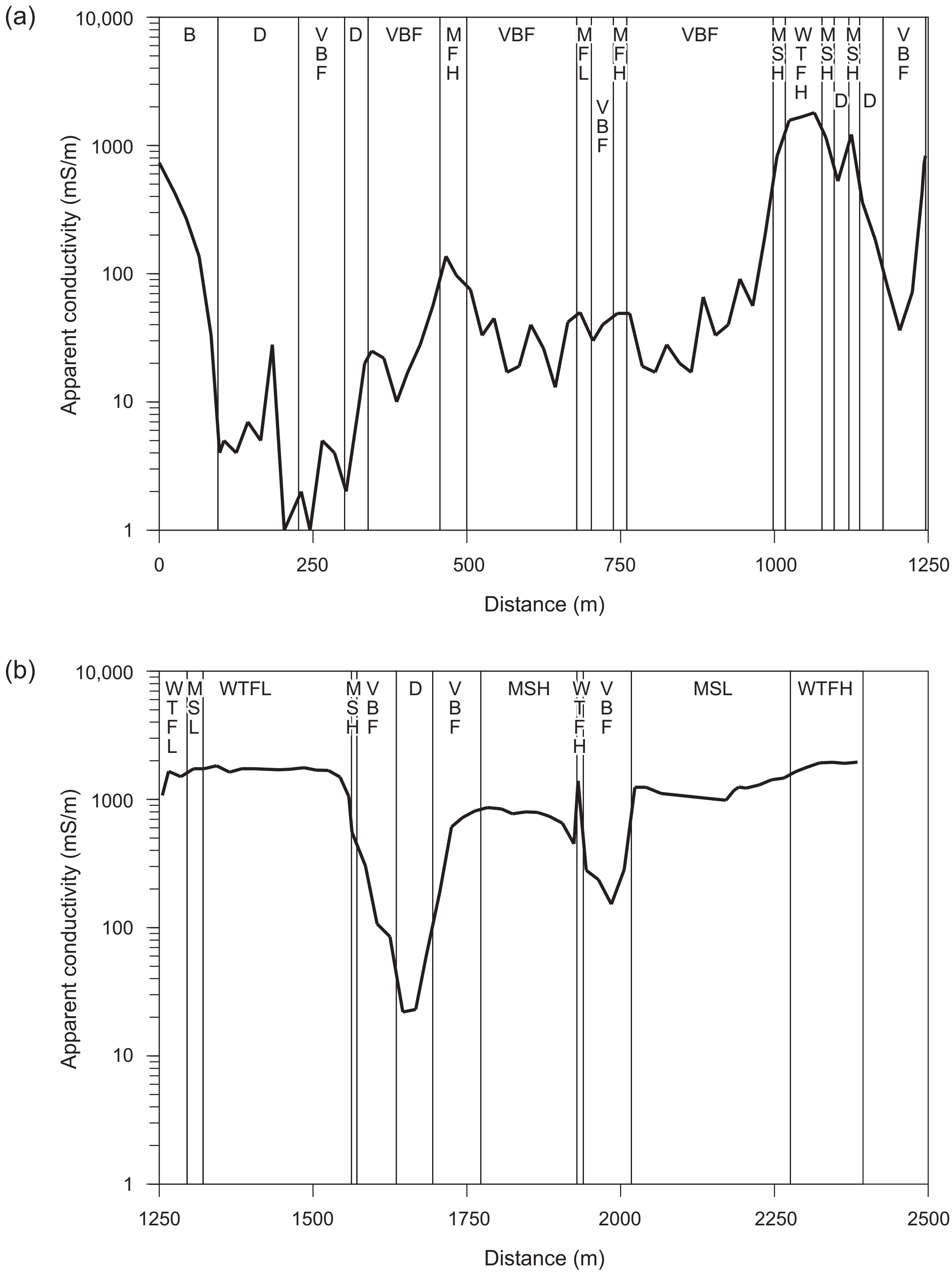

Figure 35. Apparent conductivity profile (vertical dipole orientation) superimposed with surveyed coastal environments along the PA transect (a) between 0 and 1250 m and (b) between 1250 and 2400 m from the gulf shoreline.

flats; high wind-tidal flats have a slightly higher average conductivity (1762 mS/m in the vertical dipole orientation) than do low wind-tidal flats (1643 mS/m), perhaps due to greater evaporative concentration of dissolved minerals at slightly higher elevation. Average conductivities in salt marshes remain very high (1285 mS/m in low salt marshes and 797 in high salt marshes), but are below those measured in wind-tidal flats. Average conductivities in dunes, VBF, and fresh marshes are about 100 mS/m or less, significantly below those measured in more saline environments. There is some overlap in conductivities at the upper end of the salt marsh range and the lower end of the wind-tidal flat range, as well as significant overlap among conductivity measurements in the dune, VBF, and fresh marsh environments.

Elevation, Conductivity, and Vegetation Units

There is a strong inverse correlation between elevation and apparent conductivity measured along the PA transect (fig. 36). Highest conductivities are measured where elevations are low near the gulf shoreline and in the back-island environments. Lowest conductivities are measured where higher ground is rarely flooded by saline waters, including upland (dune and VBF) environments. Relatively minor elevation increases in dominantly saline environments are accompanied by strong local decreases in conductivity.

Comparisons of elevation and conductivity measurements made for NWI units mapped at a small scale (low detail) and more detailed coastal barrier environments show that many of the habitats are statistically distinct but have ranges that overlap to varying extents. Taken together, elevation and conductivity measurements for a given location can be used to better discriminate among wetland habitat and coastal environments. For the PA transect, for example, apparent conductivities below about 15 mS/m are indicative of environments mapped as upland (U) on the 1992 NWI, as are elevations above 2 m (fig. 37a). NWI upland and estuarine (E2EM1P) units have similar elevation and conductivity values at lower elevations and higher conductivities, but field investigations suggest that many of the locations classified as E2EM1P are actually within

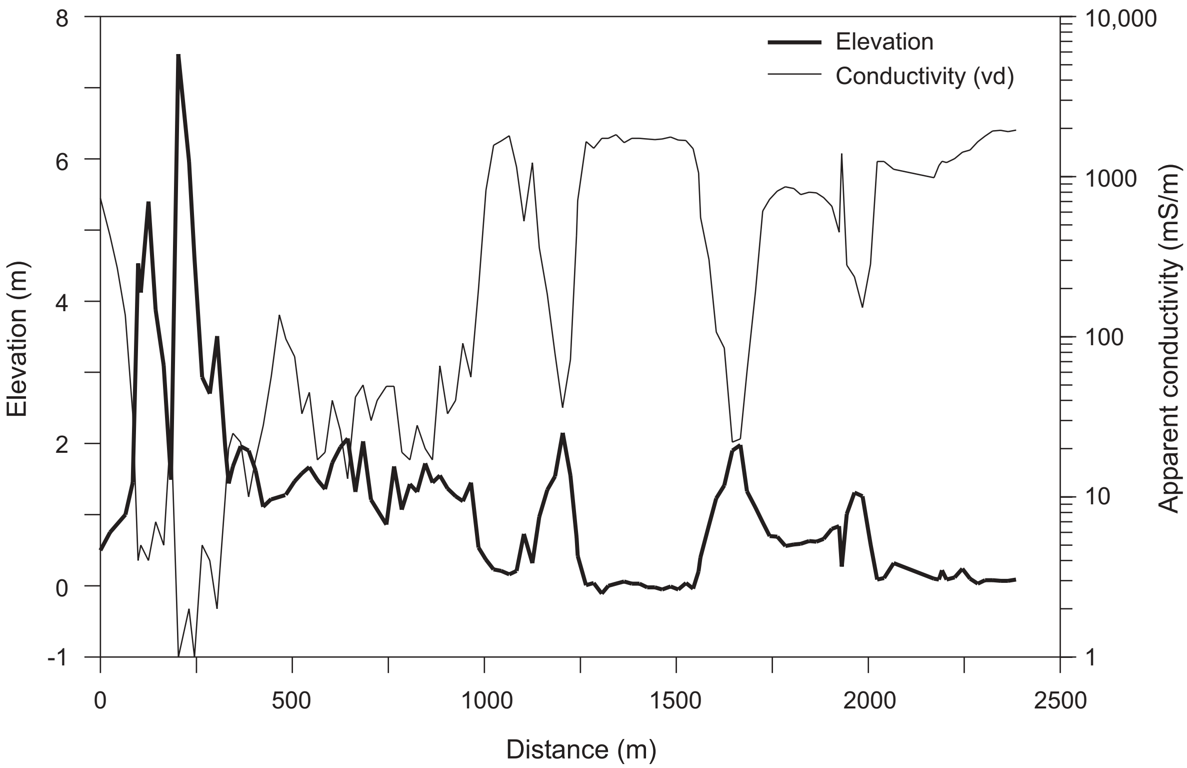

Figure 36. Elevation (heavy line) and apparent conductivity (light line) profiles along the PA transect.

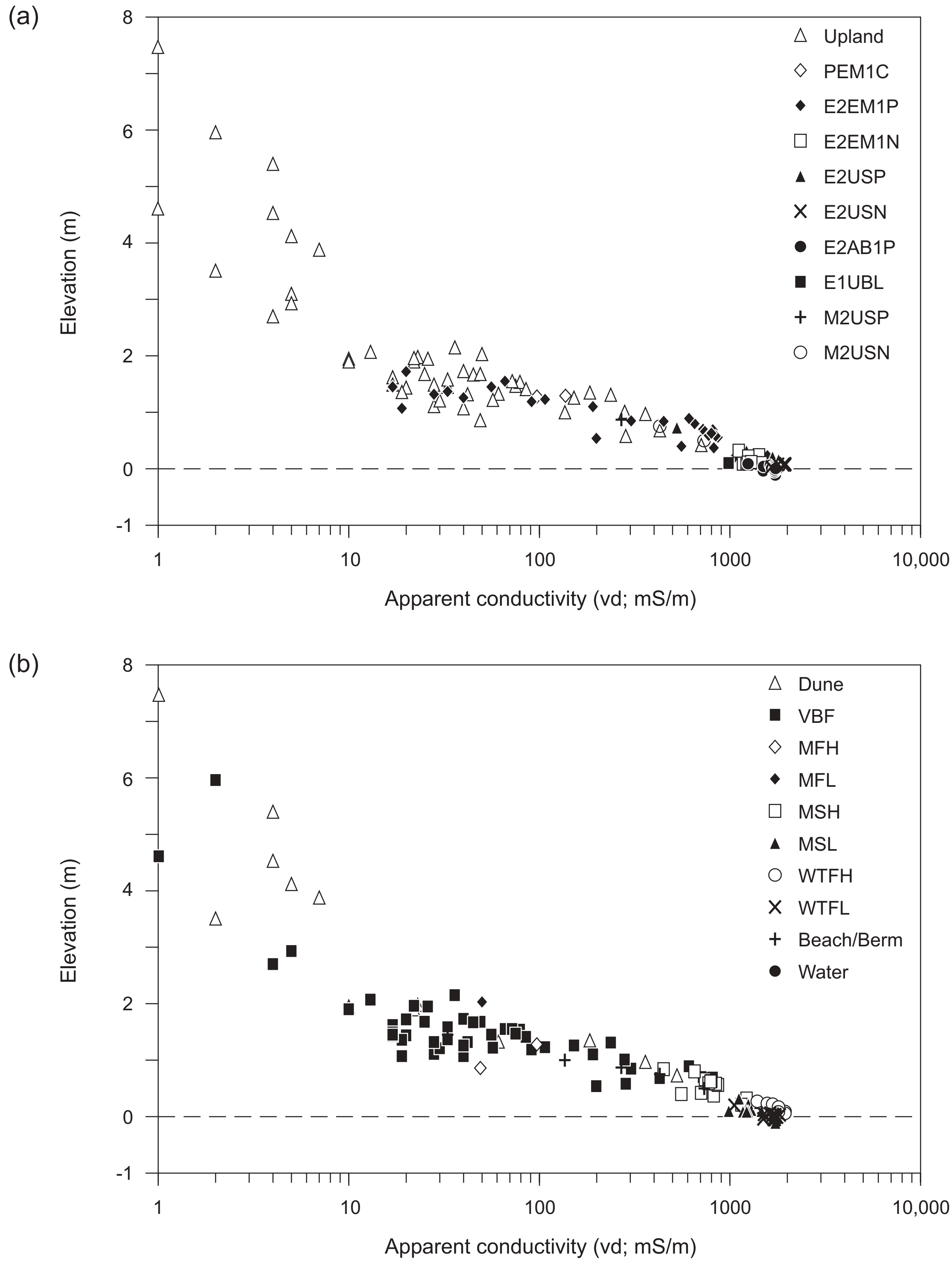

Figure 37. Elevation and apparent conductivity of (a) 1992 NWI units, and (b) coastal environments along the PA transect. Apparent conductivity measured in the vd orientation.

the VBF environment and might be more accurately classified as upland (fig. 37). NWI units with the lowest elevations (less than 0.1 m) and highest conductivities (greater than 1000 mS/m) along the PA transect include the estuarine units E1UBL, E2AB1P, and E2USN (fig. 37a and table 4). Other marine (M2USN and M2USP) and estuarine (E2USP and E2EM1N) NWI units are slightly higher and less conductive.

Among the coastal environments identified along the PA transect, the dune and VBF environments have relatively large ranges in elevation and the lowest conductivities (fig. 37b and table 5). Low elevations, limited elevation ranges, and very high conductivities are measured in the most saline environments such as low salt marsh and low and high wind-tidal flat. Slightly higher elevations and slightly lower conductivities are typical of high salt marshes. Beach and berm environments have elevations and conductivities that are similar to those of lower VBFs.

LIDAR ADVANTAGES AND LIMITATIONS

Airborne lidar offers detailed and accurate elevation measurements that can be used to help classify wetlands and associated habitats more accurately than classifications based on aerial photographs alone. Comparisons of photographically mapped NWI units with lidar-derived topographic profiles across Mustang Island show that topographic detail achieved with lidar allows more detailed discrimination of wetland and upland units than appears on NWI maps. Further, some NWI units on both island transects are misclassified; some units mapped as wetland are more likely to be upland, and some units mapped as upland are more likely to be wetland habitat. Comparisons of lidar-derived elevations with coastal environments identified during the field survey show similar levels of detail, suggesting that lidar data could be used to map coastal environments at the same level achievable with labor-intensive ground-based surveys. Used with aerial photographs, lidar-derived elevations can be used to help distinguish coastal environments as well as upland, palustrine, estuarine, and marine habitats that may have ambiguous photographic signatures.

Most NWI habitats and coastal environments have statistically distinct average elevations, but rather wide elevation ranges that overlap to varying degrees with other habitats and environments. Further, lidar may not penetrate to the ground surface in densely vegetated areas, producing an anomalous elevation at those points that may be significantly higher than the actual elevation and lead to potential misclassification of habitat or environment.

EM ADVANTAGES AND LIMITATIONS

EM instruments accurately measure conductivity of the shallow subsurface, which is highly correlated to elevation and soil salinity. Conductivity is highly inversely correlated to lidar-derived elevation on the Mustang Island transects. As was true with elevation data, EM-derived conductivities correlate well with both mapped NWI wetland and upland habitats and coastal environments surveyed in the field. EM and lidar data achieve similar levels of detail exceeding that achieved on the NWI maps. Conductivity variations measured along each transect closely track changes in coastal environment identified during the field surveys, suggesting that EM data could be used to classify coastal environments to the same level achievable with ground-based vegetation surveys. Comparisons of mapped NWI units with conductivity data acquired along the two Mustang Island transects reveal apparent misclassifications in the NWI maps, both where mapped wetland units have conductivities that indicate an upland habitat and where mapped upland habitat has conductivities that indicate wetland environments.

There are statistical differences in conductivities measured among various wetland habitats and coastal environments. For NWI units, average conductivities increase from upland, palustrine, estuarine, and marine units according to the flooding frequency. Similar trends are observed in coastal environment classes: lowest conductivities are measured within dune and VBF environments where elevated ground is unsaturated or partly saturated with fresh water. Low and high fresh marshes have higher conductivities than dune and VBF classes. Highest conductivities are measured in salt marsh and wind-tidal flat environments.

Although average conductivities for each NWI unit and coastal environment are distinct, the ranges of conductivities measured within these units overlap to varying degrees. Upland and fresh environments are most easily distinguishable from estuarine and marine units because the conductivity strongly responds to changes in salinity. Overlap in ranges can lead to misclassification of units if the classification is based on conductivity alone. Unlike lidar, EM measurements are made at a specific location rather than over an area. Whether made from ground-based or airborne instruments, EM measurements are typically presented as profiles along a path rather than surfaces over an area.

CLASSIFYING WETLAND AND COASTAL ENVIRONMENTS

Correlations between wetland habitat, coastal environment, lidar-derived elevation, and EM-derived conductivity suggest that lidar and EM data could be used to improve the accuracy of coastal habitat classification and partly automate the process. One approach would be to combine photographic, elevation, and conductivity data in a common spatial environment, using elevation and conductivity as a supplement to aid classification of ambiguous habitat signatures on aerial photographs.

A more quantitative approach would be to establish statistical elevation and conductivity characteristics for all possible habitat and coastal environment types, then use measured elevations and conductivities to classify locations according to proximity of each measurement to average elevation and conductivity for each habitat or environment. Because the statistical characteristics (average, range, and standard deviation) could be calculated for each unit, probabilities of accurate classification could be assigned for each point. Because elevations and conductivities are quite distinct between upland and fresh habitats and estuarine and marine habitats, probabilities of misclassification at this level would be low. Probabilities of misclassification among habitats with more elevation and conductivity overlap, such as between some estuarine and marine units and saline environments, would be higher.

FUTURE WORK

Although the results of this preliminary study are encouraging, many uncertainties remain before elevation and conductivity data can be used routinely and accurately in coastal habitat classification. From the lidar perspective, further work is needed to determine where vegetation density is great enough to prevent the lidar instrument from detecting the top of vegetation rather than the ground surface. In coastal areas, where errors of fractions of a meter can lead to significant habitat misclassification, methods of correcting for vegetation height become important.

From the EM perspective, we measured conductivity during winter and examined the relationship with habitat and environment based on those measurements. It is likely that conductivities within the uppermost meter of the subsurface will change seasonally with precipitation and ambient temperature, but we have not reoccupied the same sites in different seasons and at different times following precipitation or flooding events to examine the magnitude of these changes or the environments that are most susceptible to seasonal change.

We made our conductivity measurements using a ground-based instrument that explores 0.8 to 1.5 m in the subsurface. This instrument is practical for field investigations and additional preliminary studies, but is too labor-intensive for large mapping projects. Similar instruments can be towed beneath low-flying helicopters to rapidly and remotely acquire conductivity data along flight lines at an arbitrary line spacing. Airborne measurements can be made simultaneously at multiple explorations depths, enabling shallow data to be used for vegetation mapping and deeper data (to a few tens of meters) to be used for other purposes such as saline-water intrusion into coastal aquifers and geometry of the fresh-water lens that underlies many coastal barriers.

CONCLUSIONS

Elevations measured using airborne lidar correlate well with NWI upland, palustrine, estuarine, and marine units. Lidar-derived elevation profiles provide greater detail than is present in small-scale NWI maps produced from aerial photographs and can be used to help map wetland habitats more accurately and in greater detail than is possible from aerial photographs alone. Mapping detail achievable with lidar approaches that of ground-based investigations. Where vegetation is dense, lidar-derived elevations may represent the top of massed vegetation rather than the ground surface, leading to potential habitat misclassification.

Measurements of shallow electrical conductivity using a ground-based EM instrument also correlate well with both NWI habitats and coastal environments determined during ground surveys. Measured conductivities range over more than three orders of magnitude. Highest conductivities are found at locations within marine and estuarine NWI units and in salt marsh, wind-tidal flat, and forebeach environments. Lowest conductivities are found at locations within upland and palustrine NWI habitats and in dune, VBF, and fresh marsh environments. Conductivity changes along island transects are consistent with, and more detailed than, mapped NWI units. Classification detail achievable with conductivity measurements exceeds that of small-scale NWI maps based on aerial photographs.

Lidar-derived elevation and EM-derived conductivities are strongly inversely correlated and each method has advantages and disadvantages. Both methods readily discern saline- and fresh-water environments and complement traditional, photograph-based wetland classification by helping classify distinct coastal environments that have similar signatures on aerial photographs. Overlap in elevation and conductivity among some habitats and environments suggests that a statistical approach to automated wetland classification based on lidar, EM, and aerial photographs could achieve greater detail and accuracy than current methods based on aerial photographic interpretation and limited field checking.

Further evaluation of the use of lidar and EM in coastal habitat classification should include (1) characterize and minimize land-surface elevation error where vegetation is dense; (2) determine the variation in measured conductivity in the coastal environment with seasonal changes in ambient temperature and precipitation patterns; (3) evaluate whether elevation and conductivity statistics derived from coastal environments in one area can be applied to classify similar environments in other, geographically distinct areas; and (4) migrate conductivity measurements to an airborne platform where large areas can be surveyed rapidly and multiple depths can be explored simultaneously.

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APPENDIX A. MUSTANG ISLAND STATE PARK TRANSECT

Distance along the transect, waypoints, locations (easting and northing in Universal Transverse Mercator coordinates, zone 14 north, 1983 North American Datum, 1980 Geodetic Reference System), elevation (1988 North American Vertical Datum), measurements of apparent conductivity in the horizontal (hd) and vertical (vd) dipole orientation using the Geonics EM38 ground conductivity meter, habitat as classified in the 1992 National Wetlands Inventory, and vegetation characteristics encountered during the December 2003 conductivity and vegetation survey. Vegetation characteristics include height range and height of massed vegetation, soil wetness, vegetation cover percentage, and coastal environment classification. Plants identified at each waypoint are listed in Appendix C.

Distance along transect (m)	Waypoint	x (m)	y (m)	Elevation (m)	App. cond., hd (mS/m)	App. cond., vd (mS/m)	Habitat (NWI 1992)	Veg. height (ft)	Veg. mass height (ft)	Wetness	Cover (%)	Coastal environment
0	112	679695	3060671	0.34	828	707	M2USN			Wet	0	Wet beach
25	111	679673	3060682	1.02	298	322	M2USN			Damp	0	Back beach
39	110	679662	3060691	1.55	72	91	U			Dry	0	Veg line
45	109	679656	3060693	2.37	9	14	U			Dry	5	Dune flank
59	108	679643	3060698	4.21	2	3	U	2-2.5			80	Foredune crest
70	107	679634	3060704	2.43	5	9	U	0.5-0.9			30	Dune swale
85	105	679620	3060711	3.75	2	5	U	0.3-1.6		Dry	70	Dune flank
96	106	679610	3060714	5.37	1	2	U	0.5	0.5	Dry	50	Dune crest
105	104	679602	3060720	4.12	2	3	U	0.8 -2.5			80	Dune flank
125	103	679585	3060729	2.21	3	6	U	0.3-4	0.5		60	Dune flank
145	102	679567	3060739	1.92	5	8	U	0.6	0.6		30	VBF
164	101	679550	3060748	1.88	5	9	U	1	1		60	VBF
185	100	679531	3060757	2.92	2	4	U	0.8	0.8	Dry		VBF
205	99	679514	3060767	2.12	4	7	U	0.6-1.6		Dry	50	Dune
225	98	679496	3060777	2.52	3	6	U	1.5	1.5	Dry	50	VBF
245	97	679479	3060785	2.71	2	4	U	1-1.5			50	Dune flank
265	96	679462	3060795	1.80	9	15	PEM1A	1-3	2	Dry	100	VBF
285	95	679444	3060805	1.42	19	23	PEM1A	1.5	1.5	Damp	100	VBF
305	94	679426	3060813	1.20	20	24	PEM1A	1-1.4		Damp	100	VBF
325	93	679408	3060823	1.64	12	19	PEM1A	1-2.0		Damp	100	Low dune
345	92	679391	3060833	1.15	28	33	PEM1A	1.2->3		Damp to wet		VBF
365	91	679373	3060843	0.99	27	34	PEM1A	1-3		Damp to wet	100	VBF
385	90	679355	3060851	0.98	28	35	PEM1A	1-3.5				Dune margin
405	89	679337	3060861	1.46	18	30	PEM1A	1.5-2		Dry	90	Low dune
424	88	679320	3060870	0.76	34	42	PEM1A			0.5' water	50-100	High fresh marsh
445	87	679303	3060880	0.91	31	47	PEM1A	1.3	1.3	Wet	100	VBF

465	86	679285	3060889	0.98	41	60	PEM1A	1-3		Wet	100	VBF
485	85	679267	3060899	1.21	43	69	PEM1A	4.5	4.5	Wet	100	VBF
505	84	679250	3060908	0.97	39	59	PEM1A	1-3	1.4	Damp	100	VBF
526	83	679231	3060917	0.92	37	55	PEM1A	1-3.5	2	Wet	100	VBF
546	82	679214	3060928	0.95	43	63	PEM1A	1-2.6		Damp to wet	100	VBF
565	81	679196	3060935	0.70	36	48	PEM1A	1.5	1.5	Stdg. water 0.7	80	High fresh marsh
585	80	679179	3060946	1.02	35	51	PEM1A	1-3.1		Damp	100	VBF
604	79	679161	3060954	0.88	34	47	PEM1A	0.4	0.4	Stdg. water 0.1	100	Low fresh marsh
625	78	679143	3060964	0.75	30	43	PEM1A	0.8	0.8	Stdg. water 0.5'		Low fresh marsh
637	77	679132	3060970	0.82	31	40	PEM1A	6-8		Stdg. water 0.85	20	water
667	76	679108	3060986	0.74	27	25	U	0.7-7?		Stdg. water 0.7		water
678	75	679098	3060990	1.17	17	24	U	0.4-1		Damp		VBF
705	74	679072	3061001	0.52	260	288	U	3.4	3.4	Stdg. water 0.8	70	Low fresh marsh
724	73	679057	3061013	0.88	222	231	PEM1C	0.7-1.6		Stdg. water 0.7	70	Low fresh marsh
746	72	679038	3061023	0.54	258	275	PEM1C	0.8-5.3		Stdg. water 0.7	30	Low fresh marsh
766	71	679019	3061030	0.78	232	262	PEM1C	0.4-3.6	1.2	0.4' Stdg. water		Low fresh marsh
773	70	679013	3061033	0.85	240	258	PEM1C	1-4		0.6' Stdg. water		Low fresh marsh
815	69	678976	3061054	0.92	100	134	PEM1A	1.5-3.7				VBF
825	68	678967	3061058	1.59	18	31	PEM1A	2-3.5		Dry	100	VBF
844	67	678950	3061067	1.97	8	13	PEM1A	3.3	3.3		90	VBF
866	66	678931	3061078	1.67	5	10	PEM1A	2-3.8	3.7	Dry	100	Dune
884	65	678915	3061086	1.52	6	11	PEM1A	1.5-3.6	2			VBF
904	64	678898	3061096	1.54	11	18	PEM1A	2-4.5				VBF
925	63	678879	3061106	1.41	14	24	PEM1A	2-4				VBF
945	62	678862	3061115	1.13	22	37	PEM1A	1.5-3	2.8		100	VBF
963	61	678845	3061124	1.08	50	72	PEM1A	1.2-4.3		Damp		VBF
985	60	678826	3061134	1.23	136	190	PEM1C	2.3-3.7	2.8	Damp		VBF
1004	59	678809	3061142	0.96	113	181	PEM1C	2-4.8	2.3	Damp		VBF
1024	58	678791	3061151	1.06	270	370	PEM1C	2-7	2.5	Stdg. water 0.5		Low fresh marsh
1045	57	678773	3061163	0.67	270	408	PEM1C	2-1.6		Stdg. water 0.4		Low fresh marsh
1066	56	678755	3061172	0.92	221	329	PEM1C	2.7-4		Stdg. water, <0.25		High fresh marsh
1085	55	678738	3061180	1.06	106	160	PEM1C	2.5-3		Stdg. water, <0.33	100	High fresh marsh
1105	54	678721	3061191	1.01	66	92	U	3	3	Damp		VBF
1126	53	678702	3061201	2.25	6	12	U	1-3		Dry	95	VBF
1144	52	678685	3061208	2.35	4	8	U	1-2		Dry	70	Dune base (near)
1163	51	678669	3061219	5.49	2	3	U	2	2		50	Dune crest (near)
1185	50	678649	3061228	3.42	2	5	U			Dry	50	Dune flank
1205	1	678632	3061237	4.17	3	4	U	2	2	Dry	30	Dune
1224	2	678615	3061247	2.57	5	6	U	0.6-2.5		Dry	70	Dune
1243	3	678599	3061257	1.78	5	8	U	0-3		Dry	20	Dune
1265	4	678578	3061265	1.76	10	16	PEM1A	1-3		Dry	90	VBF
1285	5	678562	3061276	1.16	20	32	PEM1A	2	2	Damp	100	VBF
1304	6	678544	3061283	1.10	28	46	PEM1A	2-2.5		Damp	100	VBF
1322	7	678529	3061293	1.12	50	78	PEM1A	2-3		Damp	100	VBF

1344	8	678509	3061302	0.92	65	100	PEM1A	2-3		Damp	100	VBF
1365	9	678491	3061313	1.30	42	75	PEM1A	1.5->3	1.5	Dry	90	Low dune ridge
1386	10	678472	3061323	0.62	286	320	PEM1A	1.75-3		Damp	100	VBF
1404	11	678456	3061331	0.72	185	275	PEM1A	1-1.75		Damp	100	VBF
1419	12	678443	3061339	1.03	137	225	PEM1A	1.5-2		Dry	100	Dune ridge
1425	13	678437	3061341	0.50	514	561	PEM1A	0.8-2.7	1	Damp	100	VBF
1444	14	678421	3061351	0.38	842	852	PEM1A	0.4-1		Damp	90	High salt marsh
1465	15	678402	3061360	0.22	1163	1280	E2EM1P	0.5	0.5	Damp	60	High salt marsh
1485	16	678385	3061369	0.19	1405	1326	E2EM1P			Damp		High WTF
1504	17	678368	3061379	0.18	1312	1157	E2EM1P					High WTF
1525	18	678349	3061387	0.17	1224	1279	E2EM1N			Wet		Low WTF
1545	19	678332	3061397	0.19	1369	1313	E2EM1N	0.3	0.3	Wet	20	Low WTF
1565	20	678314	3061407	0.20	1534	1309	E2EM1N			Wet		Low WTF
1585	21	678296	3061416	0.01	1276	1255	E2EM1N	0.4	0.4	Damp	30	Low salt marsh/WTF
1604	22	678279	3061425	0.22	1405	1304	E2USP	0.5	0.5	Damp	40	High WTF/salt marsh
1625	23	678261	3061435	0.26	1469	1473	E2USP			Dry to damp		High WTF
1645	24	678243	3061443	0.10	1465	1439	E2USP			Damp		High WTF
1665	25	678225	3061453	0.24	1356	1273	E2USP	0.8	0.8	Damp	40	High WTF
1684	26	678209	3061462	0.18	1598	1507	E2USP			Damp		High WTF
1705	27	678191	3061472	0.26	1248	1262	E2USP	0.4-0.6		Damp	30	High WTF
1725	28	678173	3061482	0.26	1445	1392	E2USP	0.4-0.6		Damp	40	High salt marsh
1746	29	678155	3061492	0.29	1655	1543	E2USP			Dry to damp		High WTF
1765	30	678138	3061501	0.27	1848	1722	E2USP			Dry to damp		High WTF
1784	31	678120	3061509	0.32	1707	1622	E2USP			Dry to damp		High WTF
1805	32	678102	3061520	0.24	1856	1669	E2USP			Dry to damp		High WTF
1825	33	678085	3061530	0.29	2021	1703	E2USP			Dry to damp		High WTF
1845	34	678067	3061538	0.21	1977	1783	E2USP					High WTF
1865	35	678050	3061549	0.18	1655	1626	E2USP			Damp		High WTF
1885	36	678031	3061558	0.27	1566	1519	E2USP			Damp		High WTF
1905	37	678015	3061567	0.18	1735	1681	E2USP			Damp		High WTF
1925	38	677997	3061576	0.11	1425	1336	E2USP	0.3-0.5		Damp		High WTF/salt marsh
1944	39	677979	3061585	0.19	1357	1364	E2USP			Damp to wet		Low WTF
1965	40	677961	3061595	0.20	1643	1485	E2EM1N			Water 2 deep		Low WTF
1983	41	677946	3061604	0.21	1429	1345	E2EM1N	0.5	0.5	Wet	60	Low salt marsh
2006	42	677932	3061627	0.22	1554	1549	E2USP			Damp		High WTF
2019	43	677924	3061640	0.46	1046	1279	E2USP	0.3-0.8		Dry to damp		High WTF
2028	44	677917	3061646	0.80	505	767	E2USP	1.5-2		Dry		Low dune
2059	45	677888	3061656	0.22	1715	1592	E2EM1N			Wet		Low WTF
2090	46	677861	3061673	0.23	1494	1436	E2EM1N			Wet	5	Low WTF
2125	47	677823	3061675	0.26	1219	1192	E2EM1N	0.4-0.6		Damp	40	Berm
2126	49	677820	3061672	0.25	1227	1185	E2EM1N	0.5	0.5			Low salt marsh
2133	48	677814	3061676	0.19	1119	1106	E2EM1N	2.8	2.8	Wet	30	Low salt marsh

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APPENDIX B. PORT ARANSAS TRANSECT

Distance along the transect, waypoints, locations (easting and northing in Universal Transverse Mercator coordinates, zone 14 north, 1983 North American Datum, 1980 Geodetic Reference System), elevation (1988 North American Vertical Datum), measurements of apparent conductivity in the horizontal (hd) and vertical (vd) dipole orientation using the Geonics EM38 ground conductivity meter, habitat as classified in the 1992 National Wetlands Inventory, and vegetation characteristics encountered during the December 2003 conductivity and vegetation survey. Vegetation characteristics include height range and height of massed vegetation, soil wetness, vegetation cover percentage, and coastal environment classification. Plants identified at each waypoint are listed in Appendix C.

Distance along transect (m)	Waypoint	x (m)	y (m)	Elevation (m)	App. cond., hd (mS/m)	App. cond., vd (mS/m)	Habitat (NWI 1992)	Veg. height (ft)	Veg. mass height (ft)	Wetness	Cover (%)	Coastal environment
0	209	689766	3077172	0.50	784	733	M2USN			Wet		Beach
25	210	689749	3077191	0.75	444	428	M2USN			Dry to damp		Beach
44	211	689734	3077203	0.87	276	269	M2USP			Dry		Beach
65	212	689719	3077217	1.00	150	136	U					Beach
84	213	689705	3077230	1.45	26	33	U			Dry		Beach
98	214	689698	3077242	4.53	3	4	U	1.4-1.8			70	Dune crest
105	215	689689	3077244	4.12	3	5	U	0.7-2			70	Dune
125	216	689675	3077258	5.40	3	4	U	1-5	2.5		80	Dune
144	217	689660	3077269	3.88	2	7	U	0.8-2			70	Dune
165	218	689644	3077283	3.10	3	5	U	1.2-2		Dry	100	Interdune
184	219	689630	3077296	1.49	29	28	U	0.5-1.3		Wet	95	Interdune
203	220	689615	3077308	7.47	2	1	U	1-2.7	1		95	Dune
231	221	689595	3077328	5.96	2	2	U	0.5-2.5	1			VBF
245	222	689585	3077335	4.61	3	1	U	1.2-2.6	1.2			VBF
265	223	689570	3077350	2.93	2	5	U	1.5-3.5	2.4	Dry	100	VBF
285	224	689555	3077363	2.70	4	4	U	1.5-4	2.5	Dry	100	VBF
304	225	689541	3077376	3.51	2	2	U	1.7-3.6	2.6	Dry	100	Dune
325	226	689525	3077389	1.95	8	10	U	1.3-4	1.8	Slightly damp	100	Dune flank
334	227	689519	3077395	1.44	16	20	U	0.4-3.5		Wet	100	VBF
345	228	689511	3077403	1.68	20	25	U	1.4-4	1.8	Damp	100	VBF
365	229	689496	3077417	1.96	16	22	U	1.8-3.8	2		100	VBF
386	230	689479	3077429	1.90	6	10	U	2-3.2	2.2	Dry	100	VBF
404	231	689466	3077442	1.62	15	17	U	0.5-3	2	Damp	100	VBF
424	232	689451	3077455	1.11	27	28	U	0.3	0.3	Wet	50	VBF (disturbed)
445	233	689435	3077468	1.22	63	57	U	0.3	0.3	Damp	20	Disturbed VBF
466	234	689423	3077486		129	137	PEM1C	0.7-8	1.5			High fresh marsh

483	196	689407	3077494	1.28	78	97	PEM1C	0.7-4		Dry	50	High fresh marsh
506	197	689390	3077510	1.47	71	75	U	0.4-1		Dry	30	VBF (disturbed)
525	198	689376	3077523	1.58	19	33	U	0.5	0.5		65	VBF (disturbed)
544	199	689362	3077535	1.67	42	45	U	2-3.7	2	Dry	100	VBF
565	200	689346	3077549	1.49	10	17	U	1	1		95	VBF
585	201	689331	3077562	1.36	11	19	U	1.4->3	1.4			VBF
604	202	689317	3077575	1.73	27	40	U	1.8-3.8	1.8	Dry	100	VBF
625	203	689301	3077588	1.95	15	26	U	4.5	2	Dry	100	VBF
644	204	689286	3077601	2.07	7	13	U	1.5-2.8	2	Dry	100	VBF
664	205	689272	3077614	1.32	31	42	U	1.6-4	2.3	Damp	100	VBF
684	206	689257	3077628	2.03	41	50	U	6-7		Stdg. water	80-100	Low fresh marsh
705	207	689241	3077641	1.21	21	30	U	1.4->4	1.4	Damp	100	VBF
721	208	689230	3077653	1.07	33	40	U	0.8->2				Disturbed VBF
745	113	689211	3077668	0.86	42	49	U	0.1-0.5		Wet	100	High fresh marsh
765	114	689197	3077682	1.68	47	49	U	2->4	3.2	Dry	100	VBF
785	115	689181	3077695	1.07	13	19	E2EM1P	1-3.5		Damp	100	VBF
806	116	689166	3077709	1.43	10	17	E2EM1P	1.6-3.5		Damp	100	VBF
825	117	689152	3077722	1.32	18	28	E2EM1P	2.6-5		Damp	100	VBF
846	118	689137	3077736	1.72	13	20	E2EM1P	2.2	2.2		100	VBF
865	119	689121	3077748	1.45	11	17	E2EM1P	2-3.7			100	VBF
884	120	689107	3077760	1.55	51	66	E2EM1P	2.3	2.3		100	VBF
904	121	689092	3077774	1.37	21	33	E2EM1P	1.7-4.5	1.7	Damp	100	VBF
925	122	689077	3077789	1.26	24	40	E2EM1P			Damp	100	VBF
944	123	689062	3077800	1.19	68	91	E2EM1P	1.8-3.4	1.8	Damp	100	VBF
965	124	689046	3077814	1.45	32	56	E2EM1P	1.6-3		Damp	100	VBF
985	125	689032	3077828	0.54	200	199	E2EM1P	0.8-1		Damp	100	VBF to high salt marsh
1004	126	689018	3077841	0.37	766	822	E2EM1P	0.7	0.7	Wet	100	High salt marsh
1024	127	689002	3077854	0.23	1767	1571	E2EM1P			Damp		WTF
1044	128	688987	3077867	0.21	1788	1673	E2USP			Damp		WTF
1065	129	688972	3077881	0.16	2029	1800	E2USP			Damp		WTF
1084	130	688958	3077894	0.21	1138	1149	E2USP	0.2-0.6		Damp	60	High salt marsh
1103	131	688943	3077906	0.73	331	527	E2USP	1.3-3	1.3			Low dune
1125	132	688927	3077920	0.32	1121	1222	E2USP	0.5	0.5	Damp	20	High salt marsh
1143	133	688913	3077932	0.97	245	360	U	1.7->4	1.7		100	Low dune
1164	134	688896	3077945	1.35	111	184	U	1.8-3	1.8		100	Low dune
1184	135	688883	3077959	1.54	43	79	U	1.3-5	1.3	Damp?	100	VBF
1204	136	688867	3077973	2.15	20	36	U	1-3.5	1		100	VBF
1224	137	688853	3077987	1.55	40	72	U	1.8-4	1.8		100	VBF
1240	138	688841	3077997	0.68	340	428	U	1.2-5.5	3	Damp	100	VBF WTF edge
1243	139	688838	3077999	0.42	956	707	U	0.6-2	1	Wet	80	High salt marsh
1265	140	688823	3078014	0.01	1747	1654	E2AB1P			Very wet		Low WTF
1285	141	688807	3078027	0.04	1586	1505	E2AB1P			Stdg. water	10	Low WTF
1306	142	688792	3078041	-0.11	1937	1732	E2AB1P	0.5	0.5	Stdg. water 0.2'	5	Low salt marsh

1323	143	688779	3078053	0.00	1989	1732	E2AB1P	0.8	0.8	Stdg. water 0.15’	<10	Low WTF
1343	144	688763	3078065	0.03	2130	1828	E2AB1P			Very wet		Low WTF
1364	145	688748	3078079	0.06	1828	1628	E2AB1P			Very wet		Low WTF
1384	146	688733	3078092	0.03	2211	1732	E2AB1P			Very wet		Low WTF
1404	147	688718	3078107	0.03	2178	1732	E2AB1P			Very wet		Low WTF
1424	148	688703	3078120	-0.02	2057	1718	E2AB1P			Very wet		Low WTF
1444	149	688688	3078133	-0.02	1868	1703	E2AB1P			Stdg. water 0.1'	5	Low WTF
1463	150	688674	3078146	-0.05	2049	1717	E2AB1P	0.4	0.4	Stdg. water 0.2'	10	Low WTF
1485	151	688658	3078160	-0.01	1941	1769	E2AB1P			Stdg. water 0.2'	10	Low WTF
1505	152	688643	3078174	-0.05	1888	1694	E2AB1P			Stdg. water 0.2'	20	Low WTF
1525	153	688628	3078186	0.04	1828	1681	E2AB1P			Stdg. water 0.2'		Low WTF
1544	154	688613	3078199	-0.04	1727	1496	E2AB1P			Very wet		Low WTF
1558	155	688603	3078209	0.20	1035	1055	E2EM1P	0.7-0.8			100	Low WTF
1563	156	688600	3078212	0.40	452	556	E2EM1P	0.8	0.8	Damp	100	High salt marsh
1585	157	688584	3078227	0.85	266	303	E2EM1P	1-2	2		100	VBF
1604	158	688569	3078239	1.23	60	107	E2EM1P	2.5->4			100	VBF
1625	159	688553	3078254	1.41	49	85	U	2.5->5	2.5		100	VBF
1646	160	688537	3078267	1.90	14	22	U	2.5-3.8	2.5	Dry	100	Dune flank
1667	161	688522	3078281	1.98	14	23	U	2.0-4	2			Dune
1684	162	688509	3078293	1.33	39	61	U	2->5	2	Dry to damp	100	Dune flank
1706	163	688493	3078307	1.10	131	191	E2EM1P	2-4.5	2.5	Damp	100	VBF
1725	164	688479	3078320	0.89	599	609	E2EM1P	2.6	2.6		90	VBF
1743	165	688465	3078332	0.70	705	722	E2EM1P	2-3	2	Damp	80	VBF
1763	166	688450	3078345	0.69	731	812	E2EM1P	0.7-2	1.5	Damp	85	VBF
1784	167	688434	3078359	0.56	819	865	E2EM1P	0.2-1.4	0.7		100	High salt marsh
1806	168	688418	3078373	0.58	745	843	E2EM1P	0.4-1.8	0.8		90	High salt marsh
1824	169	688404	3078385	0.59	702	773	E2EM1P	0.6-1.5	0.6	Damp	90	High salt marsh
1846	170	688388	3078400	0.63	681	799	E2EM1P	0.4-1.2	1			High salt marsh
1865	171	688374	3078413	0.62	679	791	E2EM1P	0.4-1.8	0.9		100	High salt marsh
1884	172	688360	3078426	0.66	592	739	E2EM1P	0.4-2.3	0.7	Damp	100	High salt marsh
1905	173	688344	3078439	0.80	494	652	E2EM1P	2-3	2.5	Dry to damp	100	High salt marsh
1924	174	688330	3078453	0.84	288	449	E2EM1P	1.5-2.5		Damp	85	High salt marsh
1931	175	688324	3078456	0.27	1485	1396	E2EM1P	0.3	0.3	Dry	20	High WTF
1944	176	688315	3078466	1.01	184	280	U	2	2	Dry to damp	100	VBF
1964	177	688300	3078479	1.31	157	237	U	2-4	2	Dry to damp		VBF
1985	178	688284	3078492	1.26	88	152	U	1.7-5	1.7			VBF
2006	179	688269	3078507	0.58	183	284	U	2-3	3			VBF
2023	180	688256	3078518	0.09	1301	1245	E2AB1P	1.2	1.2	Very wet	70	Low salt marsh
2041	181	688242	3078529	0.11	1391	1243	E2EM1N			Shallow water	80	Low salt marsh
2066	182	688357	3078683	0.32	1139	1113	E2EM1N	0.1-3.5	2.5	Stdg. water	95	Low salt marsh
2171	184	688146	3078617	0.10	1041	985	E1UBL	0.4-2.9	1.5	Wet	100	Low salt marsh
2184	185	688135	3078625	0.09	1395	1171	E2EM1N	0.7-2.9	1	Wet	80	Low salt marsh
2192	183	688209	3078714	0.22	1313	1248	E2EM1N	1.3-5	2.4	Stdg. water		Low salt marsh

2204	186	688120	3078638	0.09	1457	1223	E2EM1N	0.5-2.4	2.4	Very wet	100	Low salt marsh
2225	187	688105	3078652	0.12	1469	1295	E2EM1N	0.8-2.2	1.8	Very wet		Low salt marsh
2245	188	688090	3078664	0.24	1465	1421	E2EM1N	<0.1-2		0.1' stdg. water	100	Low salt marsh
2265	189	688075	3078678	0.1	1425	1464	E2EM1N	1.3	1.3		60	Low salt marsh
2285	190	688061	3078691	0.03	1747	1652	E2USN			Wet		High WTF
2304	191	688046	3078705	0.08	1767	1788	E2USN			Damp		High WTF
2324	192	688031	3078718	0.08	2251	1930	E2USN			Damp		High WTF
2345	193	688016	3078732	0.07	2150	1949	E2USN			Damp		High WTF
2364	194	688001	3078744	0.07	2211	1911	E2USN			Damp		High WTF
2385	195	687986	3078758	0.09	2170	1950	E2USN			Damp		High WTF

APPENDIX C. PLANTS OBSERVED ALONG MUSTANG ISLAND TRANSECTS

Waypoint	Plants and Associated Environment
1	Yellow flower, Heterotheca subaxillaris?, larger flower.
2	Yellow flower, Heterotheca subaxillaris?, smaller flower.
3	Paspalum monostachyum, grasses, yellow smaller flower, Heterotheca subaxillaris?.
4	Paspalum monostachyum, Bushy Bluestem (Andropogon glomeratus)
5	Paspalum monostachyum, Scirpus pungens, Bushy Bluestem around site.
6	Paspalum monostachyum, Scirpus pungens, Spartina patens, bushy bluestem near.
7	Paspalum monostachyum, Bushy Bluestem, scattered Scirpus Pungens, VBF
8	Paspalum monostachyum, Spartina Patens, Bushy Bluestem, scattered Scirpus pungens.
9	Paspalum monostachyum, Bushy Bluestem, Spartina patens. Low dune ridge.
10	Algae. Spartina Patens, Scirpus Pungens, scattered Scirpus
11	Scirpus pungens 3+ Paspalum monostachyum , Spartina patens, Bushy Bluestem.
12	Paspalum monostachyum
13	Thick Sporobolus, short (1.3') Borrichia, scattered Spartina spartinae (2.7')
14	Monanthochloe littoralis, scattered Salicornia, Monanthochloe 0.4', scattered Borrichia ~1'. Sporobolus
15	All Monanthochloe marsh. Algal mat. Tidal flat (sand).
16	Tidal flat, algal mat, spongy. Sand.
17	Tidal flat and margin of road. Buried algal mat.
18	Tidal flat, dense algal mat draped over veg stalks
19	Tidal flat algal draped over Monanthochloe stubs, scattered.
20	Tidal flat algal covering.
21	Edge of tidal flat on low mound in Monanthochloe. Algal mat
22	Monanthochloe mound, numerous sandy burrow piles.
23	Tidal flat, sand cover over algae.
24	Tidal flat, algal mat, Monanthochloe littoralis
25	Monanthochloe littoralis flat, cover varies.
26	Tidal flat, sand over algae.
27	Monanthochloe littoralis, algal mat.
28	Monanthochloe littoralis.
29	Tidal flat, sand veneer over algal mat and short stubs.
30	Tidal flat, thin veneer of sand over algal mat—spongy.
31	Tidal flat, thin veneer of sand over algal mat—spongy.
32	Tidal flat, thin veneer of sand over algal mat.
33	Tidal flat, thin veneer of sand over algal mat—spongy.
34	Tidal flat, algal mat, small amount of sand over top.
35	Tidal flat, algal mat, firm.
36	Tidal flat, ruts causing lows and highs. Sand over algae, short dead stubs.
37	Firm tidal flats, sand over algae.
38	Edge of low vegetated mound, and tidal flat/road. Veg on mound Monanthochloe and grass.
39	Tidal flat, algal mat (light colored)
40	Tidal flat.
41	Small clump Batis maritima
42	Tidal flat, firm.
43	Camphor daisy and other composites.
44	Paspalum monostachyum in seed, aster? Fimbristylus, fire wheel in low dune area.
45	Tidal flat, dead seagrass drift.
46	Tidal flat with dead annual Salicornia, some Batis.
47	Low berm along shore, Monanthochloe.
48	Spartina alterniflora on edge of bay, mixed with scattered Batis and dead Salicornia.
49	Back (gulfward) from WP 48 in Batis. Scattered dead annual Salicornia.
50	Dune side, instrument on sand. Pocket gopher mounds, Yellow flower, Heterotheca subaxillaris? larger flower.
51	Pocket Gopher sand mounds, Yellow flower, Heterotheca subaxillaris? (larger) Veg dense in clumps. Veg 2' on dunes.
52	Pocket gopher mounds, Paspalum monostachyum 1-2' high. Larger Yellow flower, Heterotheca subaxillaris?, low ground cover.
53	Paspalum monostachyum, Bushy Bluestem, some laying down ~ dense.
54	Scirpus Pungens abundant. Paspalum monostachyum and Pennywort. Tall ~3' Scipus pungens. Possibly Spartina

patens, frogfruit near, Bushy Bluestem rare.

55 Clumps of Spartina spartinae. Abundant Scirpus pungens. Dense grass blown down by onshore wind.

56 Scirpus pungens, frogfruit, Borrichia scattered, wolfberry, dead wolfberry (S.Pungens)

57 On edge of cattail marsh, wolfberry, Borrichia. Possibly Paspalum vaginatum. Borrichia 2', Paspalum vaginatum 1.6'.

58 Cattail (7'), Clumps of Spartina spartinae, Borrichia and Paspalum vaginatum (2-2.5')

59 Spartina spartinae abundant, Bushy bluestem(4.8'), Fimbrystylis, Scattered Scirpus pungens, Spartina patens (2-2.3')

60 Spartina patens, Scirpus pungens (3.7'), Bushy bluestem, Frogfuit (2.3-2.8)

61 Boundary of VBF with abundant Bluestem and marsh with Scirpus pungens. Reading in VBF Dense marsh 1.2' and higher Bluestem 4.3'.

62 Paspalum monostachyum, Bluestem (3'), Scattered Scirpus pungens, Dense.

63 Bushy Bluestem, Spartina spartinae, dense Paspalum monostachym. Grass ~2', Bluestem 4'

64 Paspalum monostachyum, Bluestem (4.5'), Dense cover ~2'

65 Dense veg, hummocky Paspalum monostachym, Bluestem, dense 1.5'-2'. Paspalum and bluestem 3.6'

66 Vegetated dunes. Dense cover. Paspalum monostachym. Dense 2' scattered bluestem 3.7-3.8'

67 Yellow flower, Heterotheca subaxillaris? plant (larger flower), Paspalum monostachym 3.3', not as dense.

68 Dense cover.Paspalum monostachyum, Bluestem, pennywort.

69 Edge of standing water. Pennywort, Scipus pungens (3.7'), not too dense where reading was taken. Grass laying down, 1.5'

70 Scirpus pungens 4', Paspalum vaginatum? Cattail, plants laying down in water (~1') some tall Borrichia.

71 Scipus pungens lying at angle, Paspalum vaginatum? at ~ 1.2' Scirpus pungens 3.6'

72 Cover in water (dead grass covered in algae) high cattail on edge of site.

73 Algae covered Paspalum vaginatum? in water. Scirpus pungens laying down.

74 Ditch along road, dead cattail. Cover mostly dead and lying down. broken stems ~3.4

75 Mowed along highway. Paspalum vaginatum, pennywort, bluestem, swordgrass (Srirpus pungens).

76 Dead veg floating on water. 7' cattail on margin, scattered Scirpus pungens, vine (morning glory?) growing on dead stems.

77 Standing water, 20% cover, edge of cattail marsh, some dead. Morning glory growing up stems, submerged grass.

78 Matted veg lying down in water. Scirpus pungens, morning glory.

79 Matted veg lying down in water. Except for scattered Scirpus pungens, morning glory, some frogfruit.

80 Scattered Paspalum monostachyum, Scirpus pungens, bluestem, pennywort, frogfruit.

81 Scirpus pungens, morning glory, veg laying down mostly dead.

82 Scipus pungens, frogfruit, pennywort, dying umbrella grass, ground cover like Bacopa.

83 Scipus pungens, pennywort mostly dead lying down, frog fruit.

84 Scirpus pungens, pennywort, dead umbrella grass, frogfruit mostly lying down.

85 Scirpus pungens, frogfruit, pennywort that lay down.

86 Scirpus pungens (3'), pennywort, possibly Spartina patens.

87 Scirpus pungens, pennywort, frogfruit, morning glory, matted down along this area to south not as wet = bluestem.

88 100% veg except in water. Submerged in water about 50% cover Scirpus pungens, morning glory, pennywort, Spartina patens, possibly Bacopa

89 Low dune mound, Spartina patens, bluestem, pennywort, blue mist, pocket gopher mound.

90 Edge of low dune, Spartina patens,Bluestem, pennywort except on dune, 3.5' bluestem, umbrella grass dead.

91 Scirpus pungens taller than 3'. Bluestem, pennywort, umbrella grass, possibly patens.

92 Spartina patens, Bluestem, Scirpus pungens, Fibrystylis

93 Low hummocky dune, Paspalum monostachyum, Spatina patens, Yellow flower, Heterotheca subaxillaris? (larger flower), Bluestem.

94 Spartina patens, Paspalum monostachyum, umbrella grass scattered bluestem, scattered Scirpus pungens, Sporobolus?

95 Thick Spartina patens, Paspalum monostachyum, cactus nearby, Blue mist, Bluestem, possibly Spartina spartinae .

96 Thick Paspalum monostachyum, Spartina patens, larger Yellow flower, Heterotheca subaxillaris?, cactus, bluestem nearby 1-1.5, cactus and pennywort

97 Smaller Yellow flower, Heterotheca subaxillaris?, Paspalum monostachyum, cactus.

98 Cactus, smaller Yellow flower, Heterotheca subaxillaris?, dead low grass, sand, composites.

99 Sand, smaller Yellow flower, Heterotheca subaxillaris?, sparse. Dead grass.

100 Dead grass, pennywort, larger Yellow flower, Heterotheca subaxillaris?, Paspalum monostachyum.

101 Hummocky Pocket gopher mounds, pennywort, Paspalum monostachyum, smaller Yellow flower, Heterotheca subaxillaris?, low sand mounds.

102 Dead grass, sand, Smaller Yellow flower, Heterotheca subaxillaris? composites.

103 Backside of fore dune sand, composites, dead grass, smaller Yellow flower, Heterotheca subaxillaris?, scattered

bitter panicum, pennywort, Paspalum monostachyum, scattered sea oats ~4'
104 Smaller Yellow flower, Heterotheca subaxillaris?, sea oats to 2.5' scattered clumps of composites, pennywort.
105 Bare sand mounds, croton, pennywort, composites, Gulf side of dune.
106 Pennywort, sea oats, locally croton, smaller Yellow flower, Heterotheca subaxillaris?, composites, patch of sand.
107 Pennywort, small sand mounds, croton, smaller Yellow flower, Heterotheca subaxillaris?.
108 Croton, bitter panicum.
109 Face of sand dune covered with low Ipomoea (small leaf), dry sand. croton near, low.
110 Veg line averaged. Bare sand clumps of sand stabilize by Sesuvium nearby.
111 No vegetation
112 No vegetation
113 Mowed grass on edge of highway. Paspalum vaginatum, pennywort, Setaria, some Scirpus pungens.
114 Fairly dense Paspalum monostachyum, bluestem, Pennywort, S. patens? Smaller Yellow flower, Heterotheca subaxillaris?
115 Bluestem laying down 1ft.
116 S. patens, Paspalum monostachyum, Bluestem laying down 1.6 Scattered bluestems 3.5'.
117 S. patens, Paspalum monostachyum, Bluestem, small Yellow flower, Heterotheca subaxillaris? composite.
118 Yellow flower, Heterotheca subaxillaris? (small), Bluestem 2, cactus, edge of dune. Paspalum monostachyum may be most abundant.
119 Bluestem 2', S. patens, Paspalum monostachyum.
120 Spartina spartinae, Bacharis nearby, Bluestem 1 & 2,2.3 for mass, probably some Paspalum monostachum.
121 Spartina patens, Spartina spartinae, Bluestem 1&2 (4.5'), some frogfruit, mass 1.7. composites.
122 S.patens and S. spartinae possibly dominant, Pasplalum monostachyum, bluestem 2, opuntia, blue mist, composites.
123 S. patens, bluestem 2, Paspalum monostachyum, scattered Borrichia, small Yellow flower, Heterotheca subaxillaris?, veg mass 1.8.
124 Small Yellow flower, Heterotheca subaxillaris?, Bluestem 2, Paspalum monostachyum, mass 1.6, composite flowers 3' cactus nearby.
125 Distichlis or Sporobolus, Fimbristylis, Spartina spartinae near on small dune high.
126 Monanthochloe, scattered Salicornia.
127 Tidal flat, algal mat.
128 Tidal flat, algal mat, spongy.
129 Tidal flat, algal mat, spongy.
130 Monantholoe and Salicornia, burrows, high edge of WTF.
131 Spartina spartinae, Bluestem 2(3'), low dune mound, mass 1.3
132 Edge of WTF and low mound, Monanthochloe, camphor daisy, Salicornia.
133 Low mound, Spartina spartinae, Bluestem2, mass 1.7, Bluestem2 >4'.
134 Dune mound. Spartina spartinae, Bluestem 1&2,(3'+) Scattered Baccharis, Mass 1.8' Shrubs 6'+ Blues mist.
135 Bushy bluestem2 (5' locally), Paspalum monostachyum, some Opuntia, 1.3' in mass, Some composites.
136 Bluestem2 (3.5'), Opuntia, Dry sand, veg mass 1', small Yellow flower, Heterotheca subaxillaris? composite.
137 Paspalum monostacyum,Bluestem (4+’) Scattered opuntia, Blue mist, Mass 1.8', Dense veg.
138 Spartina spartinae, Fimbristylus, Bluestem2, Baccharis shrubs up to 5.5'. Several along margin of mound. Blue mist, On edge of mound near WTF. Mass 1.2-3'
139 Matted Monanthochloe(0.6') littoralis, Salicornia+Wolfberry(1-2') but scattered, Borrichia, Distichlis slightly higher toward mound. Dead annual Salicornia.
140 WTF, algal mat.
141 WTF dead Salicornia annual. Edge of standing water. Batis in water. (dead mostly)
142 On WTF. Batis(0.5), dead Salicornia, Loose algal mass in water.
143 WTF, scattered dead annual Salicornia, Batis scattered nearby.
144 Muddy, loose algal mat, scattered dead Salicornia.
145 Loose algal mat, muddy: sink up to one inch, scattered dead Salicornia.
146 WTF as before muddy, scattered dead Salicornia.
147 Muddy, loose algal, water stands in tracks.
148 Same as above except wetter.
149 WTF, loose algae, scattered dead annual salicornia and Batis.
150 WTF, Scattered Batis(0.4) and dead annual Salicornia, 0.15 standing water and loose algae
151 WTF, dead Salicornia, clumps of Batis nearby.
152 WTF, dead Salicornia, clumps of Batis,loose algae.
153 WTF, More dead annual Salicornia, loose algae.
154 Near edge of WTF, algal mat, sink to sole tops.
155 Between WTF and Bell-shaped mound. Monanthochloe (lying down in some areas) and Batis mix.

156 Distichlis or Sporobolus, Damp sand, Spartina patens, and wolfberry up toward mound nearby 0.8 Distichlis.
157 Thick Spartina patens, Scattered bluestem 1&2, also Spartina spartinae, which may be more abundant2'-3' wit sp. laying down locally 1' when lying down.
158 Very dense spartina assemblage appears to be mixture of S. patens and S. spartinae. Also bluestem. 2.5 where laying down, other 4+ also Paspalum monostahcyum, more patens verified.
159 Bluestem 2, Spartina patens (dominant), mass 2.5 tall, stem >5.
160 Very thick Paspalum monostachum, Bluestem, Spartina patens very thick and high down slope. Small Yellow flower, Heterotheca subaxillaris?, Mass ~2.5, stem ~ 3.8 Opuntia near.
161 Near crest of mound Paspalum monostachyum, Bluestem2, dead sun flower, opuntia, small Yellow flower, Heterotheca subaxillaris?, mass~2', stems up to 4' (BS2) also possibly Aster nearby.
162 Going down other side of dune. Dense veg. Paspalum monostachyum, bluestem 2, Mass2', stems 5+ possibly Spartina? definitely on down slope.
163 Dense. Spartina patens, Bluestem 2, Spartina spartinae, mass 2-2.5, stem to 4.5.
164 Spartina spartinae clumps. Wolfberry, Borrichia, clumps 2.6, bare spots on soil between clumps.
165 Spartina spartinae clumps. Borrichia, mass~2' stems 3'
166 Spartina spartinae (1.5-2') clumps. Borrichia, Monanthochloe and wolfberry. Edge Monanthochloe 0.7'
167 Dense Monanthochloe, scattered Borrichia, wolfberry(0.2-0.7) ?? 1.4 Borrichia.
168 Monanthocloe, dense Borrichia and wolfberry. Monanthochloe 0.4-0.8, other 1.8.
169 Same as above. Mass 0.6 (Monanthocloe) wolfberry and Borrichia 1.5.
170 Dense Monanthochloe(0.4-1). very scattered Borrichia(1.2) and wolfberry.
171 Same as above with more Borrichia and wolfberry. mix with Monanthochloe dominant(0.4-0.9) other 1.8.
172 Same as before 0.4-0.7 Monanthochloe, Borrichia 2.3
173 Monanthochloe (0.6), Borrichia (2'), Spartina spartinae near (2.5-3)
174 Spartina spartinae mound. Monanthochloe 1.5', stems to 2.5.
175 barrier sand flat, low Salicornia and Monanthochloe.
176 Dense veg, Spartina spartinae, Bushy bluestem 1&2, Mass 2'
177 Dense Spartina spartinae, Bushy bluestem 1&2, Mass 2', stems 3' scattered shrubs to 4' mostly Baccharis.
178 Bluestem 1 (4.5), Spartina spartinae. Baccharis near thorny shrub ?? mass~1.7 shrubs 5'. Possibly Spartina patens?
179 Near edge of mound (bell shaped) Spartina spartinae stems(3), Bushy bluestem 1&2(4), low Baccharis 4', mass~2 Blue mist.
180 Batis and some perennial Salicornia(1.2) Spartina alterniflora short 2' taller towards bay.
181 Spartina alterniflora saturated, soft, growing in shallow water. Stinky soil knee high Spartina alterniflora, mangrove shrubs.
182 Spartina alterniflora marsh. Dense cover. leaves ~2.5; 0.1 stems in same area bayward 3.5
183 Black mangrove cluster in Batis, Spartina alterniflora 2.4' Monanthochloe near. 3'-5' Batis 1.3 and also Salicornia 1.7 over knee-high to waist.
184 Edge of water body, Salicornia, Spartina alterniflora dense leaves 2.5' stems 2.9', low, some Batis 0.4-1.5'
185 Batis (0.7-1') and Spartina alterniflora leaves and stems 2.9. Water oozes into tracks. Rich organic.
186 Batis, Spartina spartinae2.4 leaves, Salicornia, water saturated, heights of Batis and Salicornia more towards bay.
187 Salicornia dense 2.2-0.8 some Spartina alterniflora 1.8', water over soles or bottom of shoes.
188 Batis (1.4') Salicornia, scattered Spartina alterniflora (2')
189 Batis 1.3, water veneer in algae, near edge of WTF
190 WTF algal mat. Firm
191 WTF Dark algal mats. Firm to spongy.
192 WTF algal mat. Firm to slightly spongy
193 WTF algal mat, spongy.
194 WTF algal mat, spongy.
195 WTF algal mat, spongy.
196 Cyperus < 0.7', mound of sand next to site ~ 4' tall. Dry sand near edge of pond.
197 Disturbed sand. Tire tracks, Eleocharis 0.7', Cyperus 1' mostly barrier dry sand.
198 Mowed grass near HWY 1 Low grass. short Paspalum monostachyum, Cyperus up to 0.5' but moist flat on ground.
199 Spartina patens, Scipus pungens, Bluestem 1&2, composite veg BF Mass 2', laying over BS~3.7.
200 1' mass high VBF Bluestem 2 other grasses Spartina patens, Paspalum monostachyum.
201 VBF Spartina patens, bluestem 2 and 1, Paspalum monostachyum, mass 1.4 Bluestem 3'+.
202 VBF 1.8 Mass, Bluestem 2 3.8'
203 Hummocky, Bluestem 2 (4.5), Panicum? sp 2' Mass, small Yellow flower, Heterotheca subaxillaris? composite.
204 VBF small Yellow flower, Heterotheca subaxillaris? composite. Paspalum monostachyum, Bluestem 2 Mass 1.5-2' also Opuntia(2.8). Scattered Bluestem 4.
205 Paspalum monostachyum, Bluestem 1&2, Spartina spartinae, 1.6-2.3' mass, some laying down bluestem ~4 very hummocky.

206 Cattail, Bacopa, Borrichia waist high, Scipus pungens 6'.

207 Other side of cattail marsh. Paspalum monostachum, Bluestem 1&2 (3.2'), Mass 1.4, Scirpus pungens 4'+

208 Roadside ditch very thick grass, thick Paspalum vaginatum and Bacopa, Setaria 0.8' mass grasses some grass 2'+

209 Middle of beach

210 Beach

211 Back beach

212 Back beach traffic area.

213 Near dune edge (flat back beach).

214 Dune crest (fore dune), Bitter panicum and composite Yellow flower, Heterotheca subaxillaris? plant veg~1.4-1.8

215 Edge of road to house on dune ridge. Yellow flower, Heterotheca subaxillaris?, Bluestem, other greens, Yellow flower, Heterotheca subaxillaris?~2' lower ground cover 0.7'

216 High dune ridge along road to house, Yellow flower, Heterotheca subaxillaris?, Bluestem, other grasses and composites. some bluestem 1-2.5' veg some (few) tall sea oats 5'.

217 Dune Paspalum monostachyum, bluestem, composites. ??

218 Paspalum monostachyum, bluestem (2'), Opuntia

219 Standing water locally, Spartina patens, scattered umbrella grass (1.3), pennywort

220 Near dune crest, Spartina patens, Bluestem, Opuntia, Yellow flower, Heterotheca subaxillaris? composite, Mass1', some~2.7, also some sea oats.

221 Paspalum monostachyum, Yellow flower, Heterotheca subaxillaris?, Opuntia, 2.5 Yellow flower, Heterotheca subaxillaris?.

222 Paspalum monostachyum, Bluestem, Yellow flower, Heterotheca subaxillaris?, Suaeda, Opuntia, Mass 1.2' other 2.6.

223 VBF assemblage, Paspalum monotachyum, Yellow flower, Heterotheca subaxillaris?, Bluestem (3.5), abundant Opuntia, 1.5-2.4, Dense veg.

224 VBF assemblage, Paspalum monotachyum, Yellow flower, Heterotheca subaxillaris?, Bluestem to 4', opuntia.

225 Low stabilized dune, Paspalum monostachyum, some bluestem to 3.6, Yellow flower, Heterotheca subaxillaris?, opuntia

226 Edge of low dune, Bluestem to 4', Paspalum monostachyum, Yellow flower, Heterotheca subaxillaris?, Spartina patens.

227 Fallen dead grass, small depression. Spartina patens, Paspalum monostachyum, Bluestem 4 0.4' dead grass, Cyperus, S. Patens 3.5, 40% lying down.

228 VBF Paspalum monostachyum, bluestem 4', Spartina patens.1.4-1.8 Mass

229 VBF low dune, 1.8-2' mass, Spartina patens, Paspalum monostachyum, Bluestem to 3.8.

230 Low dune Bluestem (3.2), Paspalum monostachyum, Spartina patens, Opuntia2', mass 2-2.2', Yellow flower, Heterotheca subaxillaris?.

231 VBF Mass 0.5-2' Bluestem 3', Spartina patens, Paspalum monostachyum.

232 Disturbed from digging and tracks. Pennywort, Spartina patens, short Bluestem, Paspalum monostachyum, mass 0.3' dead grass laying down Eleocharis ~4m wide depression leads to pond bayward mound bayward.

233 Cleared mostly barren area next to pond, sand with ruts toward pond, short grass possibly Eleocharis, 0.3 veg clumps.

234 Bacopa, Borrichia, tall dead woody plant some kind of Sesbania 6-8' 0.7-1.5 Paspalum monostachyum, Spartina spartinae clumps cattail, Sporobolus abundant.