David M. Kunz. **ECOLOGICAL EFFECTS OF RISING SEA LEVEL ON SHOREZONE.** (Under the direction of Mark. M. Brinson) Department of Biology, August 2009.

This study examines the ecological effects of sea-level rise on shorezone in the Neuse River estuary and western Pamlico Sound, NC. Shorezone is defined here in an ecohydrological context as the area of wetland that extends from an estuarine shoreline landward to where the hydrologic influence of sea level diminishes and terrestrial hydrology dominates. The thesis is structured into three chapters, each highlighting a particular scale of analysis (*e.g.*, landscape, shorezone, and plant community).

At the landscape scale, the first chapter investigates geomorphology, hypsography, wetland types, and average landscape slope of successive interstream divide units that are submerging relative to rising sea level. A geographic information system (GIS) was used to identify differences between units and translate them into a space-for-time framework consisting of four temporal stages of shorezone transgression: early – upstream migration, intermediate – non-migration, late – over-flat migration, and terminal – non-migration. The framework is intended to provide a better understanding of processes that have led to the current position of shorezones and to anticipate where effects of rising sea level will be the greatest.

In the second chapter, species composition and abundance, soil properties and elevation were analyzed at a plant community scale. Communities were arranged into a hierarchical classification according to hydrogeomorphic wetland type (landscape scale), followed by cover type (shorezone scale), and then community type (plant community scale). A detrended correspondence analysis ordination was performed to analyze samples across an apparent salinity gradient. Analyses revealed a strong relationship between soil porewater

salinity and the sequence and distance at which plant communities occur between the shoreline and the landward margin of shorezone. The results suggest that these irregularly flooded shorezones simultaneously exhibit mosaic and zonal patterns of vegetation.

At the shorezone scale, changes in cover type over time were estimated for an interstream divide unit in the outer estuary. Cover type classes were ranked to detect the extent, direction (*e.g.*, landward vs. seaward migration), and magnitude (*e.g.*, differences in rank) of vegetation change between 1958 and 1998. Cover types were delineated by interpreting aerial photographs using the GIS. Results show that seaward migration of cover types (517 ha) is more than twice that of landward migration (234 ha). This occurs in spite of an estimated 249 ha landward expansion of shorezone (*i.e.*, transgression) caused by an approximate 15 cm rise in local sea level over the 40 yr study period. This information suggests that at shorter temporal scales, vegetation change dynamics do not necessarily align with landward migration of shorezone that results from sea-level rise.

ECOLOGICAL EFFECTS OF RISING SEA LEVEL ON SHOREZONE

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by
David M. Kunz
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ECOLOGICAL EFFECTS OF RISING SEA LEVEL
ON SHOREZONE

David M. Kunz

APPROVED BY:

DIRECTOR OF THESIS ______________________________
Mark M. Brinson, Ph.D.

COMMITTEE MEMBER ______________________________
Robert R. Christian, Ph.D.

COMMITTEE MEMBER ______________________________
Enrique Reyes, Ph.D.

COMMITTEE MEMBER ______________________________
J.P. Walsh, Ph.D.

CHAIRMAN OF THE DEPARTMENT OF BIOLOGY

____
Jeffrey S. McKinnon, Ph.D.

DEAN OF THE GRADUATE SCHOOL

____
Paul J. Gemperline, Ph.D.

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Table of Contents

List of Tables

List of Figures

Foreword: Rationale for a hierarchical study

Determining the appropriate scale of an ecological study is critical (Turner *et al.* 2001). What might be an appropriate scale for studying intraspecific competition among a species is not likely to be appropriate for studying the distribution of that species across a landscape. Urban *et al.* (1987) stated that "the apparent complexity of landscapes can be partially resolved by decomposing them into a hierarchical framework." Therefore in this study, three hierarchical scales have been devised for which to conduct analyses: landscape (broad scale), plant community (fine scale), and shorezone (focal scale). In Chapter 1, how shorezone systematically changes in position, wetland type, and extent along an estuarine gradient in response to rising sea level was investigated at the landscape scale and within a space-for-time framework (Delcourt and Delcourt 1988, Picket 1989). In Chapter 2, patterns of shorezone vegetation were explored both locally and regionally at the plant community scale. Here, plant communities were arranged into a hierarchical classification that reflects the scale of each chapter. Finally in Chapter 3, cover types devised for the shorezone scale of the hierarchical classification were applied to map shorezone vegetation and its changes over a 40 year period.

Chapter 1

Effects of rising sea level on shorezone: application of a space-for-time framework at a landscape scale

Introduction

A zone of hydrologic influence is often characterized by fringe wetlands delimited by a shoreline and a landward margin where the terrestrial landscape meets an estuary. While the shoreline is influenced by factors that control erosion and deposition (Riggs 2001), the landward margin is regulated by the interaction between sea level and the groundwater table (Gardner *et al.* 2002). This zone may be regarded as the shorezone and is defined here in an ecohydrological context as the area of wetland that extends from an estuarine shoreline landward to where the hydrologic influence of sea level diminishes and terrestrial hydrology dominates.

The meaning of the term “shorezone,” however, is somewhat ambiguous and rarely defined in more than a cursory way. In a Web of Science search for the term performed in February 2009, only 13 papers were returned, most of which use shorezone in a geologic context. Only one of these papers (Ogburn-Matthews and Allen 1993) uses the term in an ecological context describing a nearshore aquatic portion of a tidal estuary in South Carolina. Howes *et al.* (1994) applied the concept to characterize intertidal and nearshore habitats in both ecologic and geologic contexts along Pacific Northwest coast of North America.

For the purpose of this study, shorezone refers to estuarine and perimarine wetlands. The concept of perimarine wetlands has not been fully developed in the US, but effectively refers to freshwater wetlands whose hydrology is directly influenced by sea level (Hageman 1969, Plater and Kirby 2006). Thus, the shorezone may extend a considerable distance landward where topography permits. While a shorezone may be inundated entirely by fresh water from a terrestrial environment, as for freshwater tidal marshes (Odum 1988, Conner *et* *al.* 2007), sea level effectively acts as a dam to freshwater input and is ultimately responsible for maintaining water levels at or near the soil surface (Nuttle and Portnoy 1992).

For most of the world's shorelines that are experiencing a relative rise in sea level, shorezones are sustained by the vertical accretion of autochthonous or allochthonous material at a rate comparable to rising sea level (Cahoon *et al.* 2006). Without this capability, the shorezone and its respective biological communities would drown.

Shorezones occupy a variety of geomorphic settings as sea level intersects land. In low-lying coastal areas of North Carolina, USA, these inherited settings can be roughly grouped into river valleys and interstream divides, or flats (*sensu* Wells 1928, Daniels 1978, Phillips 1997), the latter dominating the region. Shorezones are well developed on these settings because of their inherently low slope. Three sequential stages of development have been identified in response to rising sea level (Brinson 1991a). Initially, the landward margin of shorezone begins by migrating up river valleys or floodplains, normally the flattest part of any landscape (*i.e.*, upstream migration). Once sea level inundates valleys, the landward margin of shorezone migrates over the more gently sloping interstream flats. In the third and final stage, sea-level rises above the highest elevations. Landward margins of shorezones from opposing shorelines meet as there is no more land to migrate upon, and the result is a non-migrating island. These three stages represent a sequence in time, which may be reflected in a spatial progression where the regional slope along an estuary sets up a gradient of decreasing exposure to a rising sea level. This space-for-time approach can provide a framework for predicting how rising sea level interacts with a given landform (Pickett 1989, Michener *et al.* 1997, Desantis *et al.* 2007).

The space-for-time framework is applied to the Neuse River estuary, North Carolina, to reveal a progression of shorezone development along an estuarine gradient. Hypsographic profiles are used in concert with relative abundance and adjacency of hydrogeomorphic classes of wetland and average landscape slope to illustrate this progression. In so doing, the approach is intended to provide a better understanding of processes that have led to the current position of shorezones and to anticipate where effects of rising sea level will be most influential.

Study Area

The study area is situated in the lower coastal plain of North Carolina in the lower Neuse River watershed sub-basin, (Figure 1-1). The Neuse River flows toward Pamlico Sound, a relatively shallow lagoonal estuary separated from the Atlantic Ocean by an extensive chain of barrier islands. Astronomic tidal influence is significantly diminished in the estuary due to its few tidal inlets relative to the large volume of Pamlico Sound. Astronomical tidal amplitude ranges only 15 - 19 cm (Cahoon *et al.* 1995) and is not responsible for inundating the marsh platform (Brinson *et al.* 1991b). Instead, inundation of shorezone is largely a response to wind direction and stress (Giese *et al.* 1985). Relative sea-level rise within this system has been estimated by Poulter (2005) at between 3.2 – 4.3 mm yr^{-1} (mean of 3.8 mm yr^{-1}) using tide-gage data and by Horton *et al.* (2006) at 3.7 mm yr^{-1} based on diatom assemblages from the past 150 years.

The Atlantic coastal plain exhibits a succession of geomorphic terraces that are the result of several Pleistocene sea-level cycles (Strahler 1973). The study area occupies portions of the Talbot and Pamlico terraces (Figure 1-1). The terraces are composed of sediments of shallow marine to estuarine origin (Mixon and Pilkey 1976). The Talbot terrace is situated to the west and generally exhibits elevations greater than 6 m above sea level. To the east, the Pamlico terrace is generally situated below 3 m elevation (NOAA 2005). The two terraces are separated by the Suffolk Shoreline paleo-shoreline that formed during a late-Pleistocene sea level high stand (Mixon and Pilkey 1976). Over time, subaerial weathering and erosion has incised these terraces forming river valleys between a succession of relatively flat interstream divide areas (Wells 1928).

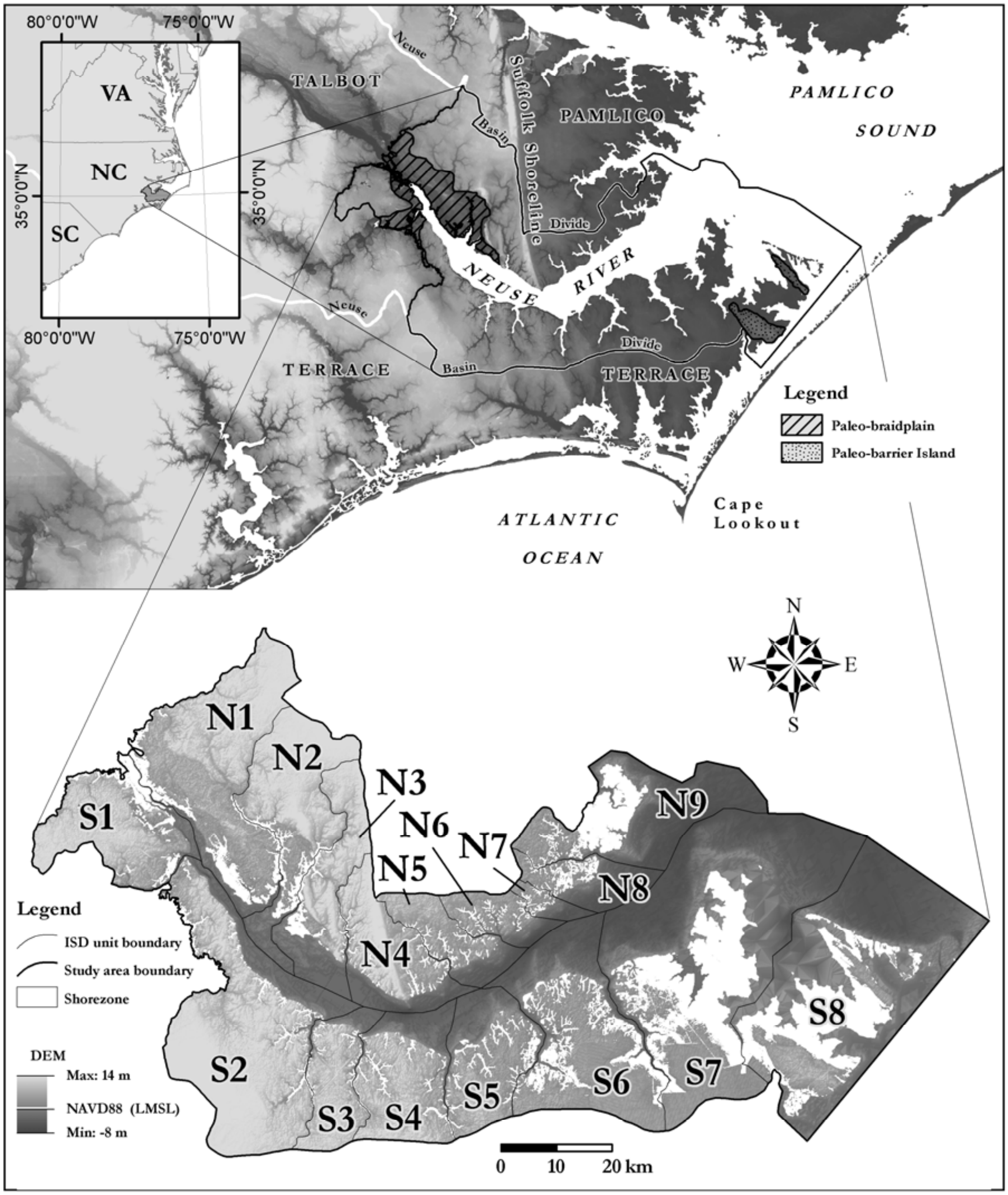


Figure 1-1. Study area location, regional geomorphic features, DEM, interstream divide units and distribution of shorezone. The position of the study area along the Atlantic Coast is depicted at top left. Regional geomorphic features are depicted at top right. Interstream divide units and the areal extent of shorezone (in white) are superimposed on the DEM at bottom.

Two important subaerial late Pleistocene features interrupt the geomorphology of the terrace settings (Figure 1-1). First, an abandoned paleo-braidplain is situated on the floor of the Neuse River valley. This paleo-braidplain is exposed in the western portion of the study area along the Neuse River. During the most recent glacial maximum (18 to 20 kyr BP), this braidplain presumably extended to the edge of the continental shelf. It has since been reworked and inundated by Holocene sea-level rise, which in turn formed the present Neuse River estuary. Second, two successive paleo-barrier islands are situated atop the Pamlico terrace in the southeastern-most portion of the study area (Mixon and Pilkey 1976). These features exhibit the highest elevations east of the Suffolk Shoreline.

Methods

Using a digital elevation model (DEM) consisting of both topographic and bathymetric data, the study area was divided into 17 interstream divide units. Units are labeled N1 through N9 on the north shore of the estuary and S1 through S8 on the south shore (Figure 1-1). The units represent increments along multiple environmental gradients (*e.g.*, salinity, elevation, slope, degree of inundation, etc.) that extend from the inner estuary (west) to the outer estuary (east). Each unit was delineated according to the thalweg of major tributaries branching from the trunk estuary, the thalweg of the Neuse River, and the north and south basin divides (Figure 1-1). Major tributaries included the widest and generally longest reaches that extended to within 1 km of the north and the south Neuse basin divides. The boundaries of unit S8 were somewhat arbitrarily defined due to limited bathymetric information in its vicinity, as well as the likelihood that Holocene sedimentation has affected the original bathymetry. The boundaries of Unit S1 also stray from the criteria described above because the DEM did not cover it completely; it was truncated using the two largest tributaries within the confines of the DEM.

Environmental Systems Research Institute ArcGIS® 9.1/9.2 software (ERSI 2004) was used to perform geographic manipulations and analyses in this study unless otherwise noted. All geographic data were projected to the North Carolina State Plane coordinate system (units in meters) cast to North American Datum 1983.

The DEM is a composite of NC Floodplain Mapping Program LIDAR topographic data and National Ocean Service bathymetric survey data of the North Carolina coast (Hess *et al.* 2004). The DEM exhibits a resolution of 6 m (*e.g.*, 36 m^2/cell) with a horizontal accuracy of ± 2 m for the LIDAR data (*i.e.*, positive values) and ± 30 m for the bathymetric sounding data (*i.e.*, negative values) (Hess *et al.* 2004). Vertical accuracy of the LIDAR data is estimated at ± 0.20 m while bathymetric data accuracy is estimated at ± 0.30 m (Hess *et al.* 2004). Both topographic and bathymetric values reference the North American Vertical Datum 1988 (NAVD 88); thus all elevation values reported in this chapter are relative to NAVD 88. Local mean sea level (LMSL) of Pamlico Sound was assumed 0.00 m NAVD 88 (Hess *et al.* 2004); however, Poulter and Halpin (2008) point out discrepancies of ±0.06 m between the NAVD 88 and the LMSL. Topography and bathymetry data are separated at 0.0 m in the DEM.

The GIS Wetland Type Map developed by the North Carolina Division of Coastal Management was also employed for this study (hereafter referred to as "the wetland map"). The wetland map is a composite of digitized US Fish and Wildlife Service National Wetland Inventory (NWI) maps, county soil survey maps, and land cover maps derived from 30 m Landsat TM satellite imagery. Map attributes describe both habitat type and hydrogeomorphic (HGM) class (*sensu* Brinson 1993) of wetland (NCDENR 2003a). The wetland map achieves nearly 90% accuracy overall, but varies considerably by class. Estuarine and riverine HGM classes were mapped with the greatest accuracy (97% or higher), while headwater and flat classes were less accurate (between 65% and 75%) (NCDENR 2003b). To improve this level of accuracy, adjustments were made to headwater and flat classes where erroneous class designations in the wetland map were obvious. These edits accounted for less than 1% of the map area and were later verified in the field. The specified minimum mapping unit for the dataset is 0.4 ha, well within the scale of this study.

Topographic differences between units were compared using hypsographic profiles (*i.e.*, cumulative frequency distributions of elevation). The hypsographic profiles include areas above and below sea level so as to encompass the entire landform and capture as much of the sequence of rising sea level as practicable. Hypsographic profiles differ from traditional hypsometric curves (*sensu* Strahler 1952, Oertel 2001, Brocklehurst and Whipple 2004) in that only the areal data are normalized along the x axis while the elevation data remain absolute along the y axis. Resulting plots are oriented so that the curve simulates a generalized profile of the unit to illustrate the vertical position of each unit relative to sea level. To produce the hypsographic profiles, the DEM was reclassified into 1 m intervals and partitioned into the interstream divide units. This generated 17 raster files each with attribute tables summarizing the number of cells (*i.e.*, the area) between each 1 m contour interval. Attribute tables were then imported into MS Excel® where the data were plotted as hypsographic profiles.

All wetlands situated between 0-1 m elevations were designated as shorezone. This range was determined by statistically sampling only the LIDAR portion of the DEM that corresponded with fresh or salt/brackish marsh habitat types in the wetland map. The mean elevation of marsh adjacent to open estuarine water was estimated at 0.487 m. Two standard deviations (s = 0.255 m) were added to the mean to arrive at an upper threshold, 0.997 m (rounded to 1 m). This rationale was established under the assumption that fresh and salt/brackish marsh habitats adjacent to estuarine waters are hydrologically controlled by sea level in Pamlico Sound. Morris *et al.* (2005) used a similar approach with LIDAR to calculate the median elevation of marsh at North Inlet, SC. The Zonal Statistics function available through the ArcGIS® Spatial Analyst extension (ERSI 2004) was used to calculate the mean and standard deviation of shorezone elevation.

To determine the areal extent of shorezone, cells containing values between 0 and 1 m were masked from the DEM and intersected with the wetland map. This shorezone wetland map was then intersected with interstream divide unit polygons. Wetland HGM classes (*e.g.* flat, headwater, riverine, and estuarine) within the shorezone were quantified and expressed as the relative proportion of the total area of shorezone for each unit. Adjacency of shorezone to HGM classes of non-shorezone wetland classes and upland areas situated beyond its landward margin were calculated to demonstrate the relative proportion of classes subject to overland migration at each unit. The length of shoreline relative to HGM class of wetland or upland was also determined and expressed as the proportion of the total length of shoreline of each unit. These data were derived using the extract raster edge function via Hawth's Analysis Tools 3.27 extension after the vector shorezone wetland map was rasterized to the same resolution as the DEM.

Lastly, average rates of landward migration of shorezone were compared to average rates of shoreline erosion. Landward migration of shorezone was estimated in two different directions, up-valley and laterally from the valley, for each unit. Both rates of migration are controlled by the rate of sea-level rise and landward slope. Up-valley slope of shorezone was measured between the 1 and 2 m contours along the sinuous length (*i.e.* run) of the valleys between two adjacent units. The two distances were averaged for a single value to perform the calculation for slope, rise (1 m) over run.

Lateral slope of the shorezone for each interstream divide unit was therefore calculated as the rise (1 m) divided by the average width (distance) between the 0 and 1 m contour intervals. Average width was determined by calculating the average length of the two contours and dividing by the respective area. For units N9, S7, and S8, the majority of land between 0 and 1 m elevations is a result of accreting peat, and thus has masked the original Pleistocene surface needed to accurately estimate landward migration. To overcome this problem, slopes between the 1 and 2 m elevations were used instead. With a value for the average distance between contour lines and a given rate of sea-level rise, an approximate rate for landward migration of shorezone is predicted. The following equation was used to estimate the potential annual rate of horizontal migration, m_i, for each unit:

$$m_i = \frac{w_i * R}{r_i}$$

where w_i is the average distance between contours, R is the rate of sea-level rise (assumed 3.8 mm yr^{-1}), and r_i is the vertical rise (*e.g.*, 1 m).

To determine a range of erosion rates at each interstream divide unit, two approaches were used. The high range of erosion rates were derived from the data of Cowart (2009). These rates are considered high because only exposed shorelines of the of the Neuse River trunk estuary were studied. Each unit was assigned the corresponding high erosion value according to the Cowart classification (*e.g.*, innermost, inner, outer, and outermost positions of the estuary). Where unit polygons shared shorelines classified differently by Cowart, the two erosion rates were averaged. To develop a lower estimate of erosion, ten locations were sampled in the inner-most portions of tributaries using the same georeferenced aerial photographs as Cowart *et al.* (in review). Only erosion rates measured along wetland shorelines (*i.e.*, shorezones) were used.

Results

The study area encompasses 2,548 km^2 and spans 94 km along the length of the of the Neuse River estuary (Figure 1-1). Vertical relief ranges 22 m, from -8 m at the mouth of the estuary in the east to roughly 14 m on the highest interstream divides of the Talbot terrace in the west (NOAA 2005). This corresponds to an approximate slope of the study area, including bathymetry and topography, of 23 cm/km (0.02%).

Greater than half the area of the easternmost units N7 (50%), N8 (63%), N9 (66%), S7 (59%), and S8 (88%) is situated below sea level (0 m) (Table 1-1). Units directly to the west, N6 and S6, are 21% and 30% submerged, respectively. At the western extreme of the study area, only 10% of unit N1 and 7% of unit S1 are submerged. By using area of water as a surrogate for time, this expected pattern illustrates that outer estuary units have been exposed to effects of rising sea level much longer than those of the inner estuary.

The hypsographic profiles provided insight into where sea level is positioned relative to the dominant geomorphic settings of each interstream divide. Beginning with unit N1, sea level intersects the landward slope at the left side of the profile, very low relative to the rest the landform (Figure 1-2a); here, shorezone is restricted to Holocene floodplains and the lowest portions of the paleo-braidplain. Interstream divide flats of the Talbot terrace are situated well above sea level. Unit N1 therefore represents an early stage in the progression of exposure to rising sea level and the concomitant migration of shorezone over the landscape. Toward the middle estuary, sea level intersects the steepest intervals of unit S4 (Figure 1-2b), equivalent to the valley wall location on the N1 curve. Here, shorezone is also restricted to the valley although a greater proportion of the unit is inundated, reflecting a later stage in the progression. With >60% of unit N8 embayed (Figure 1-2c), sea level is

Table 1-1. Area and relative percent of water, land, and shorezone of interstream divide units. Percent of shorezone relative to land excludes area of water.

Unit	Water (below sea level)		Land (above sea level)		Shorezone (relative to land)	
	hectares	percent	hectares	percent	hectares	percent
N1	1,822	8	20,427	92	1,551	8
N2	811	6	13,013	94	651	5
N3	757	7	9,394	93	494	5
N4	466	5	9,555	95	237	2
N5	410	7	5,324	93	159	3
N6	403	10	3,602	90	147	4
N7	240	16	1,289	84	66	5
N8	1,605	32	3,466	68	313	9
N9	8,916	59	6,297	41	2,814	45
S1	1,611	13	10,647	87	1,106	10
S2	807	3	26,976	97	508	2
S3	249	4	6,737	96	118	2
S4	580	5	10,514	95	309	3
S5	1,039	10	9,136	90	491	5
S6	4,068	20	16,183	80	1,898	12
S7	24,708	58	18,089	42	9,083	50
S8	22,553	63	13,199	37	7,230	55

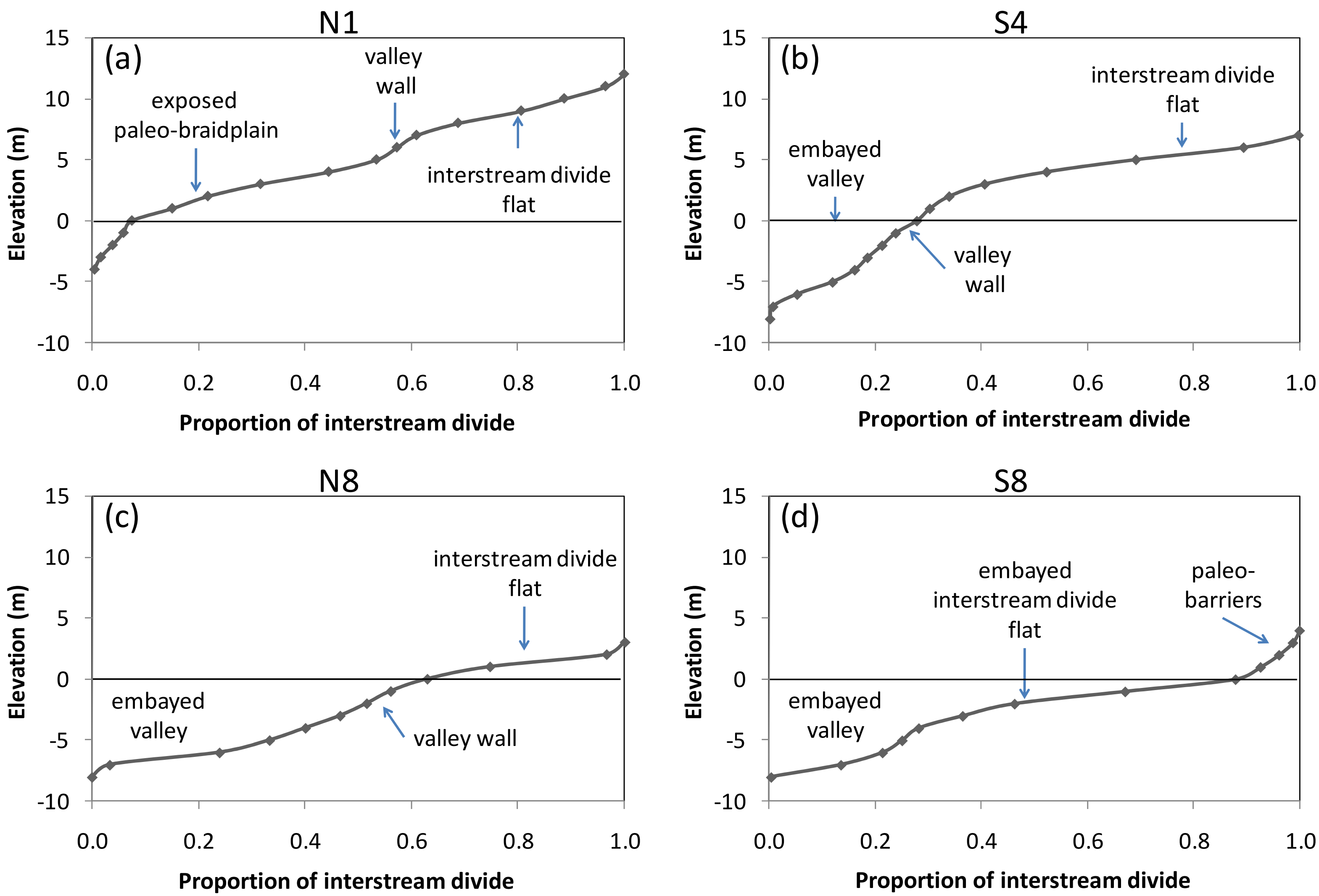


Figure 1-2. Hypsographic profiles of selected interstream divide units. Present sea level is at 0 m.

positioned just below the broad interstream flat, the flat portion of the hypsographic profile. This suggests that rising sea level will soon (*i.e.*, in the next 300 yr or sooner) lead to a rapid expansion of shorezone across the flat. At unit S8, nearly all of the interstream flat is embayed (Figure 1-2d); here, shorezones have buried the antecedent interstream flats, and all that remains above sea level are the paleo-barrier islands. These shorezones have been maintained primarily through biogenic accretion to maintain themselves above sea level. This analysis demonstrates how hypsographic profiles may be used to interpret the relationship between sea level and landscape geomorphology, and thus various stages in shorezone development.

The percentage of shorezone occupying each unit increases substantially from the inner to the outer estuary (Table 1-1). Shorezone comprises greater than half of the subaerial landmass of units N9, S7, and S8, but less than 15% of the remaining units. The sharp decline in proportion of shorezone occurs at units N8 and S6. The hypsographic profile of unit N8 reveals that sea level is at an inflection point where the steep slope would have limited the extent of shorezone in comparison with the flatter portion of the curve landward (Figure 1-2c).

Hypsographic profile analysis also helps to explain an ancillary pattern of wetland type (*i.e.*, estuarine, riverine, headwater, and flat) that emerges from the inner to the outer estuary (Figure 1-3). Toward the inner estuary, sea level is low relative to interstream divide topography; therefore, riverine wetlands dominate the shorezone (Figure 1-4). In the outer estuary, broad expanses of estuarine wetlands are dominant followed by flat wetlands near the landward margin where sea level intersects the interstream flats. Proportions of flat wetlands are high for inner estuary units N1, N2, and N3. Here, flat wetlands have

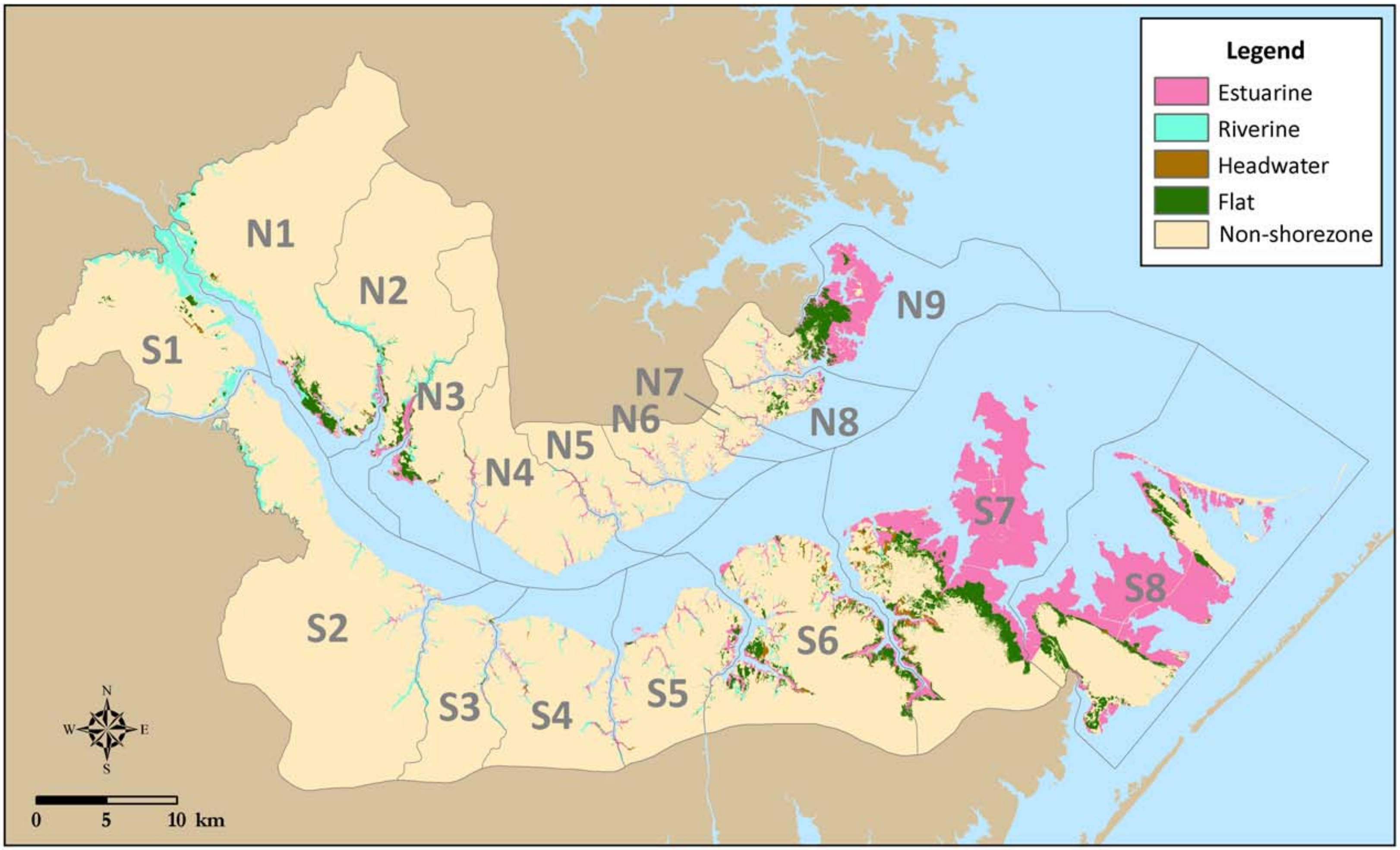


Figure 1-3. Distribution of shorezone wetland types across the study area.

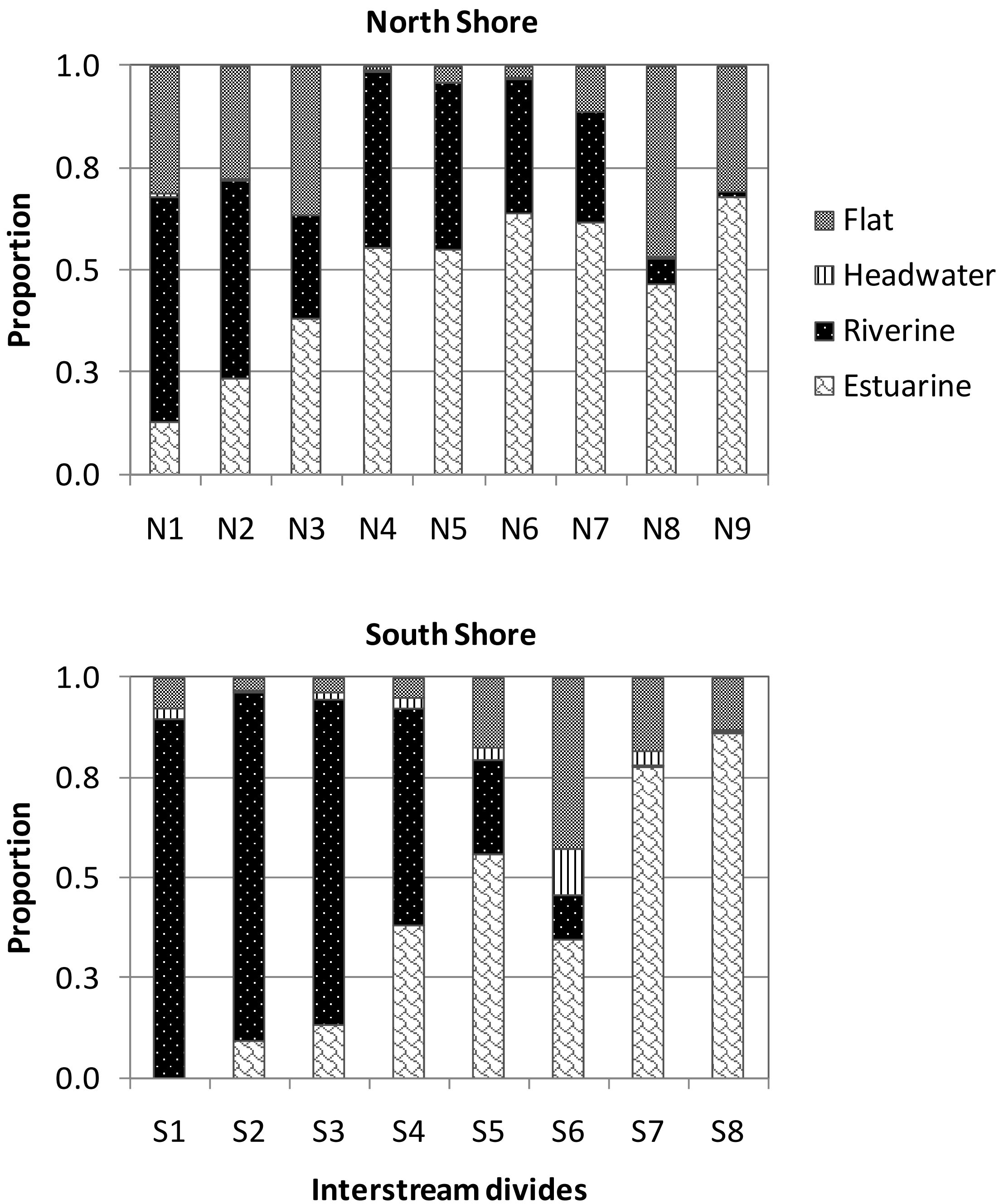


Figure 1-4. Hydrogeomorphic classes of wetland as the relative proportion of the total area of shorezone for each interstream divide unit.

developed on the abandoned paleo-braidplain. East of unit N3, the proportion of flat wetlands declines due to submergence of the paleo-braidplain Figure 1-1. Flat wetlands increase in abundance again toward the outer estuary as interstream flats are intersected by sea level. The increase in flat wetlands toward the inner estuary is not, however, repeated on the south shore because the Neuse River has incised the south side of the paleo-braidplain, a common characteristic of other lower coastal plain drainage systems of the region (Stanley Riggs, personal communication 2008). Headwater wetlands account for only a small percentage of shorezone and appeared to be inconsistently mapped; therefore, they did not provide useful information in this analysis.

The relative adjacency of wetland and upland areas at the landward margin of shorezone can be used to infer the type and proportion of non-shorezone wetland or upland most likely to be affected by rising sea level (Figure 1-5). The increase in adjacency to riverine wetlands and the decrease in adjacency to flat wetlands toward the inner estuary are comparable to the patterns of riverine and flat wetlands in Figure 1-4. From this pattern it can be inferred that shorezone is migrating primarily over riverine wetlands in the valleys of the inner estuary while migration is occurring primarily over flat wetlands in the outer estuary. Adjacency of shorezone to upland peaked at just over 50% at unit N6 on the north shore of the middle estuary, but no strong pattern of upland adjacency was present among southern shore units. High proportions of adjacency to upland areas imply steeper slopes, and thus little or no landward migration of shorezone. Consistent with this idea, the proportion of shoreline length occupied by shorezone wetland types is low in this region of the estuary because shorelines are eroding directly into steep scarps dominated by uplands rather than wetlands (Figure 1-6).

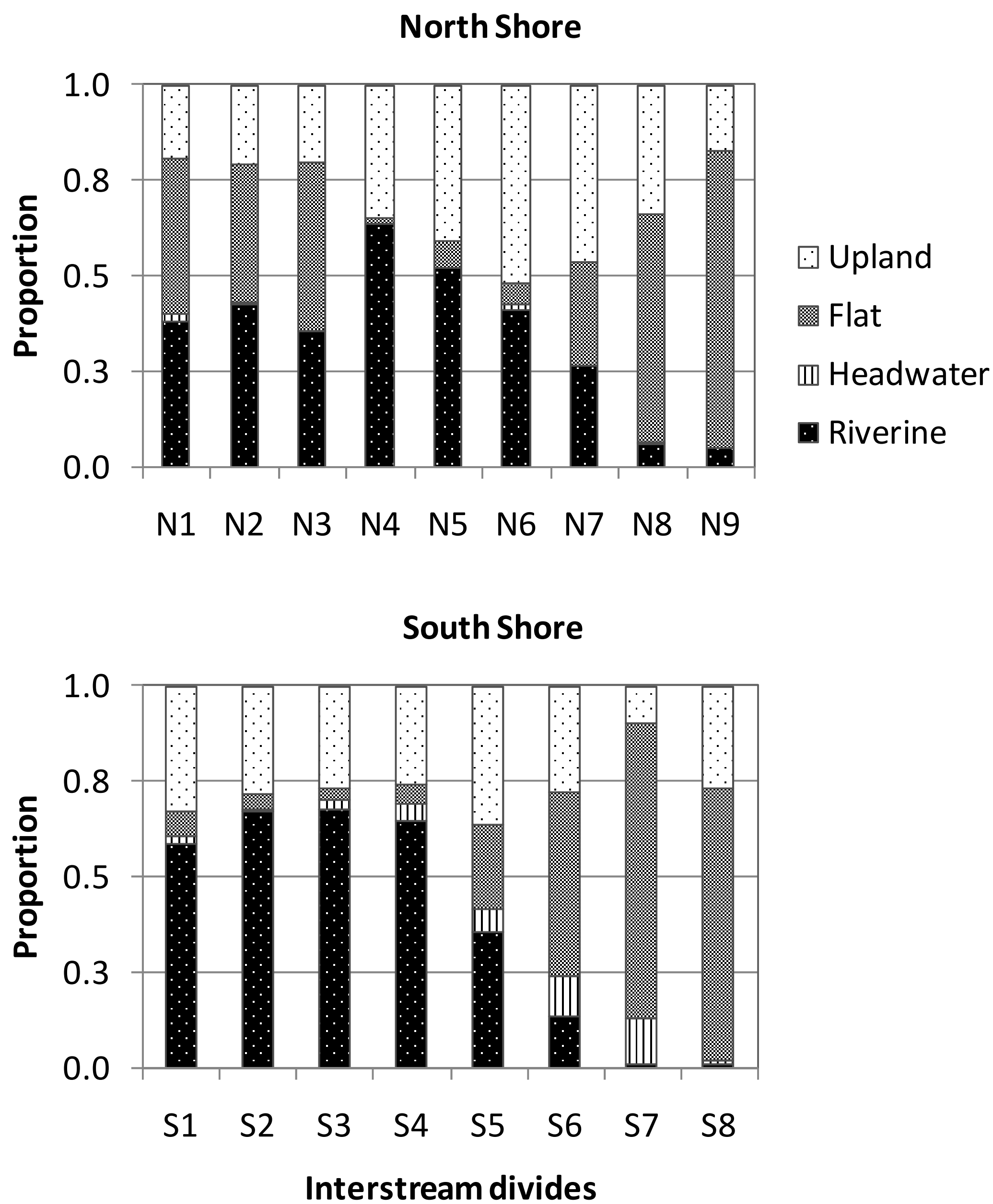


Figure 1-5. Proportion of the total length of landward margin adjacent to non-shorezone wetlands types and upland for each interstream divide unit. The estuarine wetlands are not present beyond the landward margin.

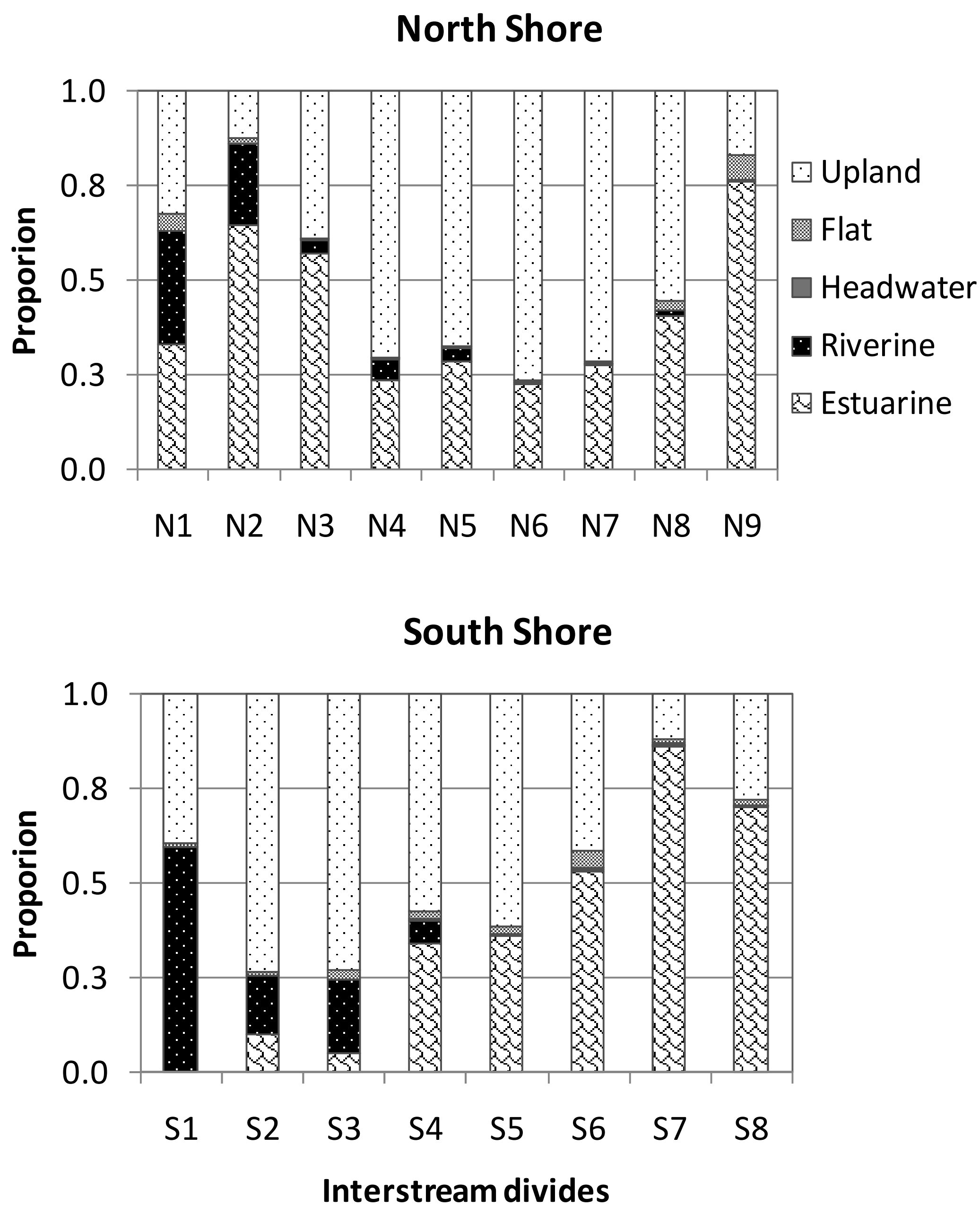


Figure 1-6. Proportion of the total length of shoreline occupied by each wetland type and upland at each interstream divide unit.

Lateral slope is least for outermost estuary units (Table 1-2). This can be attributed to the close proximity of sea level to the elevation of the interstream flats. In contrast, similar patterns of low slopes toward the inner estuary reflect the abandoned paleo-braidplain and the broad floodplains. Steepest slopes occur through the middle estuary particularly at and west of the Suffolk Shoreline (units N4, S3 and S2). Unit S8 exhibits a relatively steep landward slope in spite of its outer estuary position and abundance of estuarine wetlands. This can be attributed to the paleo-barrier found there.

Up-valley slopes are considerably lower than lateral slopes. Up-valley slopes are lowest in the inner estuary but increase through the middle estuary (units N4 through N7 and S4 through S6) (Table 1-3). They decrease again in the outer estuary because valleys are largely submerged and interstream flats dominate the subaerial landscape.

Estimates for average rates of potential landward migration range from as low as 0.16 m y^{-1} (unit S3) to as high as 3.26 m y^{-1} (unit S7) (Table 1-2). These data were derived from the same measurements used to calculate average landscape slope, and thus follow the same pattern. Average rates of overland migration are compared to an estimated range of erosion rates to help reveal whether a particular unit can be expected to gain or lose shorezone over time (Table 1-2). Inner and outer units exhibit the greatest potential for shorezone to expand. Hence upstream and over-flat migration processes prevail in these areas. Middle estuary units exhibit the least potential for shorezone expansion in the near future as the majority of valleys are embayed and interstream flats are positioned at elevations well above sea level. Provided that past rates of sea-level rise and erosion continue, the prognosis for inner and outer estuary shorezone wetland development appears strong. Should the rate of relative sea-

Table 1-2. Estimated average lateral slope, rate of overland migration, range of shoreline erosion, and range of potential shorezone loss or gain.

Unit	Average lateral slope (%)	Average rate of lateral migration* (m/yr)	Range for rates of shoreline erosion** (m/yr)	Range for lateral shorezone loss / gain (m/yr)
N1	0.42	0.89	0.05 - 0.46	0.43 - 0.84
N2	0.44	0.86	0.05 - 0.46	0.40 - 0.81
N3	0.58	0.65	0.05 - 0.52	0.13 - 0.60
N4	1.51	0.25	0.05 - 0.54	-0.29 - 0.20
N5	1.44	0.26	0.05 - 0.50	-0.24 - 0.21
N6	1.32	0.28	0.05 - 0.54	-0.25 - 0.23
N7	0.91	0.41	0.05 - 0.57	-0.16 - 0.36
N8	0.50	0.75	0.05 - 0.57	0.18 - 0.70
N9	0.24	1.54	0.05 - 0.57	0.97 - 1.49
S1	0.50	0.75	0.05 - 0.46	0.29 - 0.70
S2	1.63	0.23	0.05 - 0.52	-0.29 - 0.18
S3	2.34	0.16	0.05 - 0.58	-0.42 - 0.11
S4	1.48	0.25	0.05 - 0.54	-0.29 - 0.20
S5	0.88	0.43	0.05 - 0.50	-0.07 - 0.38
S6	0.40	0.93	0.05 - 0.54	0.39 - 0.88
S7	0.11	3.26	0.05 - 0.57	2.69 - 3.21
S8	0.51	0.74	0.05 - 0.57	0.17 - 0.69

* Based on 3.8 mm/yr relative rise in sea level (i.e. mid-point of range calculated by Poulter (2005)).
** High shoreline erosion rates from Cowart et al. (in review). Low rates derived from ten randomly selected locations along shorelines of tributaries throughout the study area.

Table 1-3. Estimated average headward slope, rate of overland migration, rate of shoreline erosion, and estimated of shorezone gain.

Unit	Average headward slope (%)	Avg. rate of headward migration* (m/yr)	Avg. rate of headward erosion** (m/yr)	Est. headward shorezone gain (m/yr)
N1	0.06	6.59	0.50	7.09
N2	0.05	6.96	0.50	7.46
N3	0.07	5.27	0.50	5.77
N4	0.14	2.68	0.50	3.18
N5	0.19	2.00	0.50	2.50
N6	0.17	2.24	0.50	2.74
N7	0.11	3.37	0.50	3.87
N8	0.10	3.79	0.50	4.29
N9	0.05	7.63	0.50	8.13
S1	0.03	11.15	0.50	11.65
S2	0.04	10.28	0.50	10.78
S3	0.09	4.20	0.50	4.70
S4	0.14	2.76	0.50	3.26
S5	0.16	2.35	0.50	2.85
S6	0.16	2.35	0.50	2.85
S7	0.06	6.47	0.50	6.97
S8	0.03	11.072	0.50	11.57

* Based on 3.8 mm/yr relative rise in sea level (*i.e.* mid-point of range calculated by Poulter (2005)).
** Shoreline erosion rates derived from ten randomly selected locations along shorelines of tributaries throughout the study area.

level rise increase, however, it is questionable as to whether shorezones will be able to keep pace through biogenic accretion.

Discussion

The sequence of shorezone dynamism identified in this study reflects a range of positions and lengths of exposure to the influences of sea level along a continuum between inner estuary valley and outer estuary interstream flat settings (Figure 1-7). Further, the space-for-time approach recognizes the large amount of variation (riverine, flat, etc.) that shorezone encompasses, but organizes them into a logical pattern based on their progressive development.

For any particular interstream divide unit, stream valleys are the first areas to be affected by rising sea level because of their low elevations. Therefore, upstream migration of shorezone is most prevalent in the inner estuary where it occurs initially over riverine wetlands of Holocene floodplains followed by flat wetlands of the abandoned paleo-braidplain. Units N1, N2, and S1 are characteristic of the upstream migration stage (Figure 1-8a). The hypsographic profile of unit N1 (Figure 1-2a) illustrates how sea level intersects only the lowest portions of the valley floor. The extent of estuarine wetlands, which are comprised of brackish marshes, is small in the inner estuary because low salinities allow swamp forest (riverine) to persist in spite of the hydrodyamics being generally controlled by sea level fluctuations (Brinson *et al.* 1985, Hackney *et al.* 2007). Consequently, riverine wetlands dominate the shorezone of this inner region.

In middle portions of the estuary, an intermediate phase of non-migration (Figure 1-7b) occurs as opportunities for overland migration of shorezone in valleys are restricted to the upstream direction due to steep lateral slopes. Shorezone becomes sparse and stream valleys open up to subtidal habitat/estuarine waters where lateral rates of erosion exceed those of lateral migration (Table 1-2), indicating that shorezone migration at the unit level

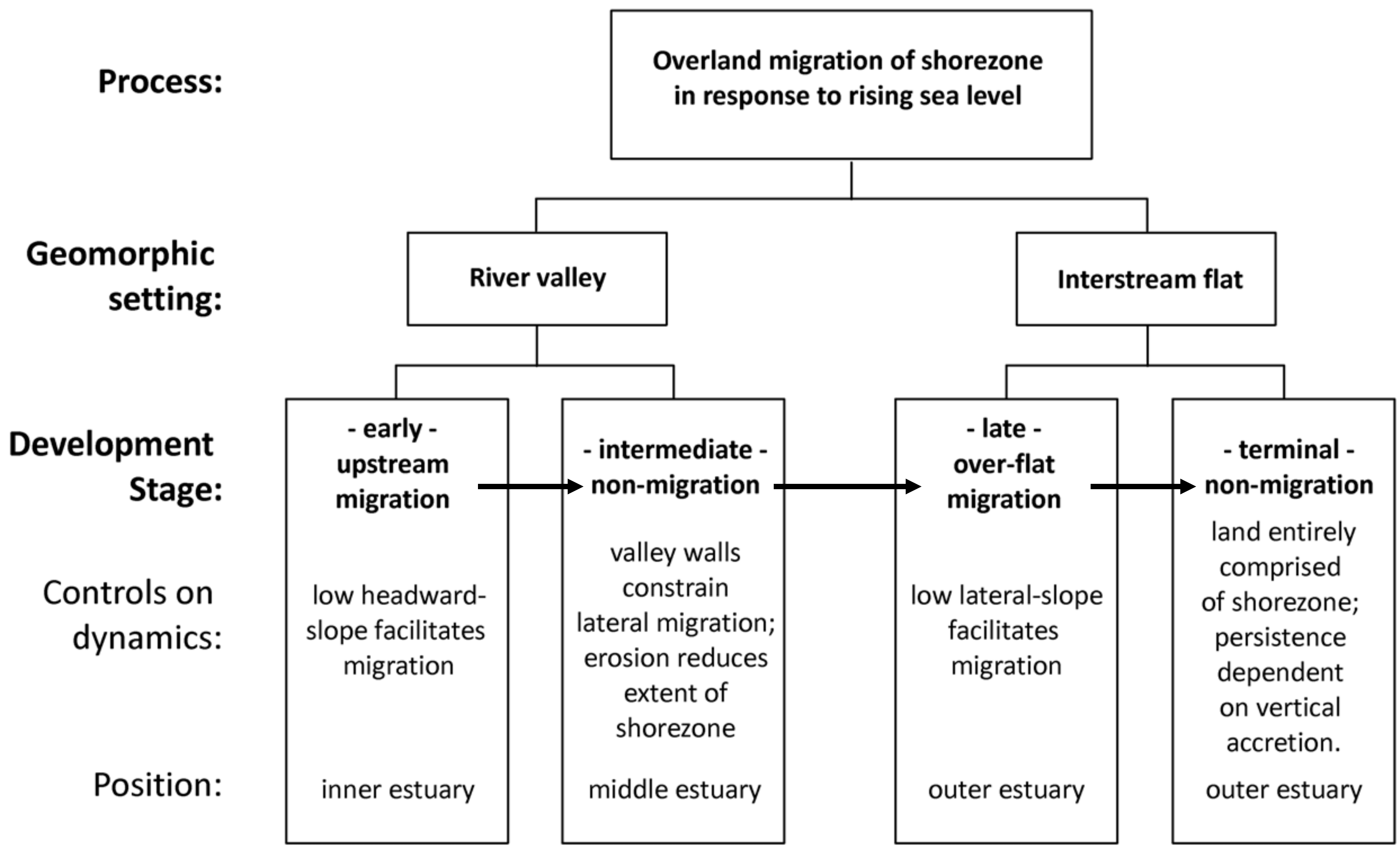


Figure 1-7. Conceptual diagram explaining the developmental stages of wetlands within the space-for-time hierarchical framework.

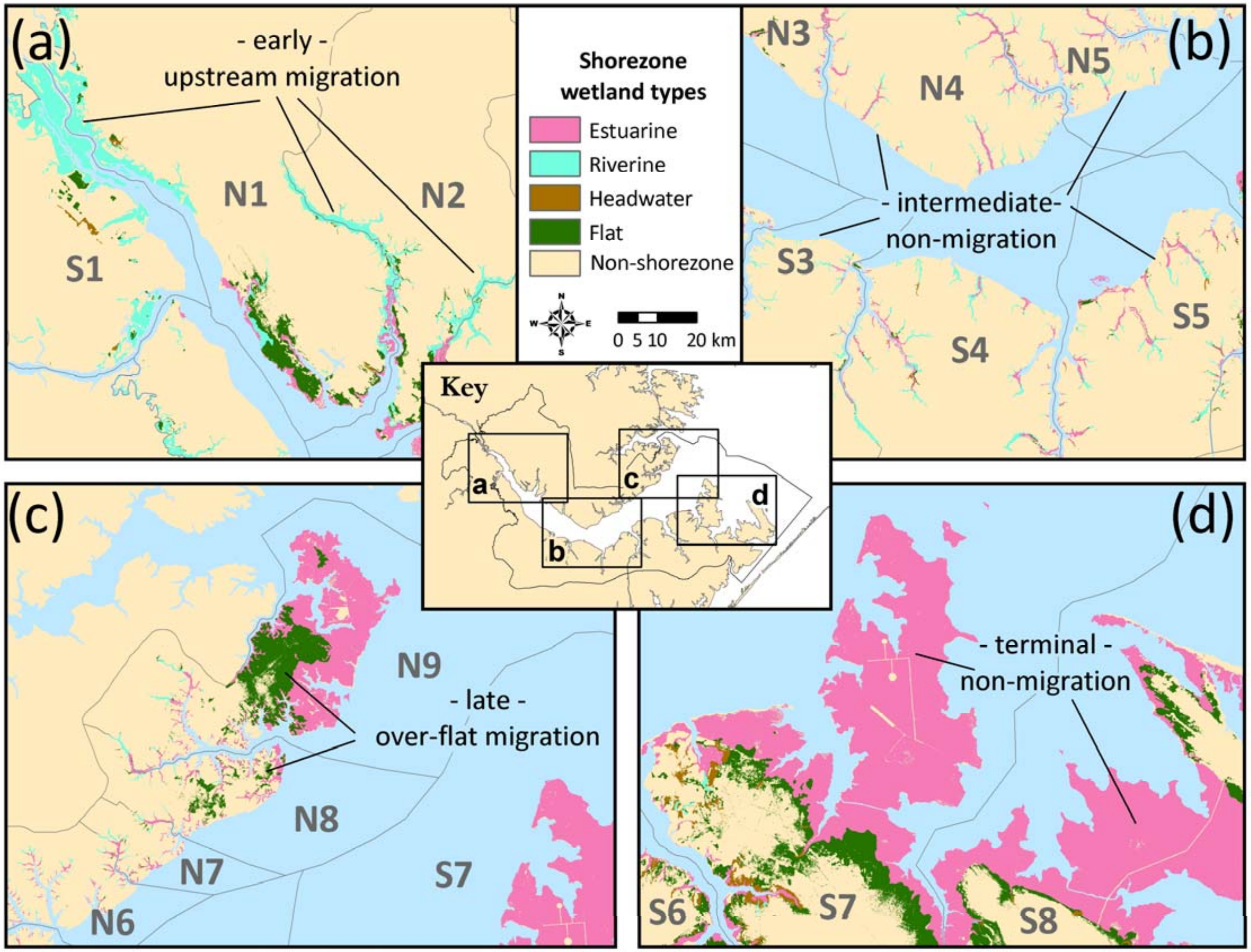


Figure 1-8. Developmental stages of shorezone from the inner to the outer Neuse River estuary.

has stalled against valley walls. Consequently, only small fragments of shorezone cling to the embayed valley walls or are restricted to the upstream portions of smaller tributaries protected from excessive erosion (Figure 1-8b). Shorezone is further reduced by greater headward slope that slows upstream migration (Table 1-3). This pattern is apparent in the middle estuary where upland classified shorelines reach high proportions (Figure 1-6). The adjacency of shorezone with uplands would be expected to show this same pattern (Figure 1-5); however, the pattern can not be detected because of discrepancies between the wetland map and the DEM at finer scales (*e.g.*, in narrow tributary shorezones of middle estuary units).

Where rising sea level has reached the transition between valley and interstream flat (*e.g.*, N8; Figure 1-2c), low lateral slopes provide the setting for landward migration to exceed shoreline erosion again. Over-flat migration dominates in the outer estuary because the valleys are submerged and riverine wetlands transitioned to estuarine and eroded (Figure 1-8c). The large proportion of flat wetlands at the landward margin (Figure 1-5) is indicative of over-flat migration. In this region, the low slopes allow the rates of migration to exceed those of erosion as illustrated by units N9, S7, and S8 (Table 1-2). Dominance of the shorezone by estuarine wetlands reaches its maximum toward the outer estuary as sea level and consistent exposure to salinity completes the shift to estuarine marshes (Figures 1-4 and 1-8d) and as observed elsewhere (Williams *et al.* 2003, Poulter 2005). If salinity was very low in this area, these wetlands would be forested flats as they are in the Albemarle Sound region (Moorhead and Brinson 1995).

Once the highest elevations of an interstream divide become hydrologically influenced by sea level, virtually no land remains for shorezone migration. Rather, shorezone persists through vertical accretion until their transition to subtidal habitats through erosion of the shoreline. While none of the units in this study is entirely exemplary of the terminal non-migration stage, portions of some units are. For example, the northeastern portion of unit S7 and the central portion of unit S8 (Figure 1-8d) are characteristic of this stage, as there is no separation between opposing shorelines dominated by estuarine wetlands. Further, were it not for the presence of the paleo-barrier islands (Figure 1-2d), unit S8 would be completely encompassed by shorezone and presumably there would be no upland areas present for overland migration to occur. This is equivalent to the non-migrating island stage of Brinson (1991a).

The space-for-time approach revealed that shorezones systematically change in position, wetland type, and extent along an estuarine gradient in response to rising sea level. In the first two stages - initial upstream migration and intermediate non-migration - shorezones are restricted mostly to valleys. In the final two stages - over-flat migration and terminal non-migration - shorezones are located mostly on interstream flats as valleys have long since submerged. Hypsographic profiles, relative area, adjacency, and migration/erosion analyses collectively provide details of the space-for-time framework.

Most other models that have been designed to predict the response of wetlands to rising sea level do not incorporate the shorezone concept consisting of a migrating landward margin and an eroding shoreline edge (Kana *et al.* 1988, Park *et al.* 1989, Poulter and Halpin 2008). Instead, they identify a future sea level elevation, and superimposed it on current topographic surfaces. Because shorezone occupies only a narrow vertical range (usually <1 m, McKee and Patrick 1988, Morris *et al.* 2002), projections of future shorelines skip over shorezones and establish a shoreline at a higher topographic contour (*e.g.*, commonly referred to as the "bath-tub" approach). In so doing, projected maps do not explicitly recognize shorezone. Consequently, such studies are silent on the nature of future shorelines as to whether they border wetlands, beaches, eroding cliffs, or some other feature. As such, no assumptions are made regarding the state of future shorezones except to infer that they will likely be inundated and lost. While it is acknowledged that accelerating rates of rising sea level may indeed drown existing shorezones (Cahoon *et al.* 2006), this is because they are unable to "keep pace" with rising sea level through vertical accretion, not because the shoreline has migrated landward to a higher elevation.

Assuming that shorezones "keep pace" with rising sea level, they will not be "lost," but rather will migrate landward to the adjacent surface, whether the surface is upland or a wetland type not yet affected by sea level stand (*i.e.*, non-shorezone wetland). In much of the Pamlico Sound region, large areas of non-shorezone wetlands are positioned adjacent to the present shorezone. Much of this land use is allocated to conservation and wildlife management (*e.g.*, Alligator River, Pocosin Lakes, and Cedar Island National Wildlife Refuges; North Carolina gamelands). Here, public lands are being converted, from upland and non-shorezone wetland to shorezone by rising sea level and secondly from shorezone to open water through erosion. The focus in these areas is on the eroding shoreline margin as it converts to subtidal habitat, a process that is often perceived as losing land due to rising sea level. In fact, land loss for the past several hundred years has been primarily due to shoreline erosion, not rising sea level (Riggs and Ames 2003). However, in other areas of the Atlantic and Gulf coasts of North America where rising sea level has outpaced vertical accretion of marshes, losses appear to occur mostly in the interior of marshes rather than at shorelines

(Kearney *et al.* 1988, DeLaune *et al.* 1994, Stevenson *et al.* 2002, Shirley and Battaglia 2006).

Riverine wetlands and uplands tend to dominate the landward margin of inner and middle estuary shorezones of the Neuse River (Figure 1-5). With emphasis on different controls and patterns along the estuarine gradient, inferences can be drawn from the space-for-time approach that might not otherwise be apparent. For example, public policy and management might be adapted toward strategically committing resources to respond to rising sea level (Poulter *et al.* 2009). Where rates of shorezone migration are potentially rapid, policies oriented toward accommodating migration might be favored. Alternatively, protection of land would be favored where large historic and societal investments are embedded in municipalities and other valuable properties. The role of the sediment source in shoreline processes should be evaluated where slope is too steep and erosion too great to accommodate shorezone. The future of shorezone is particularly important in coastal North Carolina due to widespread occurrence of negligible landward slope and an abundance of freshwater forested wetlands that are hydrologically influenced by sea level (Brinson 1991a, Moorhead and Brinson 1995, Titus and Wang 2008). The space-for-time approach provides a structure to classify shorezone according to geomorphic settings, to associate these settings with stages of development, and to infer controls on shorezone dynamics (Figure 1-7). The approach is less useful at finer scales, such as that of individual property owners, given that the average estimates of migration and erosion apply to whole interstream divide units rather than ownership parcels. While the high vertical resolution made available by LIDAR could be applied at the parcel scale, no attempt was made to do so in the interest of focusing on larger patterns and processes.

The migration/erosion perspective emphasized in this paper is applicable only to shorezones that vertically accrete at a rate comparable to rising sea level. Historically, coastal wetlands have persisted for several millennia as evidenced by the age of basal peat deposits, up to several meters deep (Redfield 1972, Orson *et al.* 1998, Young 1995). The landward margin of shorezone is established as a function of sea level. By focusing on this boundary, in addition to shoreline, estimates of landward migration necessarily encompass those processes responsible for vertical accretion, including adequate sediment deposition and organic matter accumulation. Landscape models in the Mississippi Delta and elsewhere take this into account through conversion from uplands to wetlands and from wetlands to open water (Brinson *et al.* 1995, Reyes *et al.* 2000, Martin *et al.* 2002).

Chapter 2

A hierarchical classification of irregularly flooded shorezone plant communities and associated patterns: a plant community scale analysis

Introduction

Shorezones of North Carolina have been distinguished as either regularly flooded by astronomical tides or irregularly flooded generally by wind tides (Wilson 1962, Titus and Strange 2008). Throughout the world, a typical pattern of plant community zonation has been found to occur between the shoreline and a landward margin of regularly flooded shorezones, particularly salt marshes (Adams 1963, Teal and Teal 1969, Mitsch and Gosselink 2000). While much attention has been paid to the ecology and dynamism of tidal salt marshes over the past century, irregularly flooded nanotidal shorezones, such as those that dominate the Albemarle Pamlico (A-P) estuarine system in North Carolina, have been little studied. That the A-P system is the second largest estuary in the United States underlines the importance of forming a stronger understanding of these ecosystems and particularly their fate with regard to rising sea level.

Wells (1928) was one of the earliest studies to recognize vegetation patterns in salt marshes of North Carolina. While he emphasized hydroperiod and geomorphic setting as factors controlling influencing plant community composition and abundance, he did not specify the hydrodynamics or the specific locations that he studied. Works by Brown (1959), Burk (1962), and Cooper and Waits (1973) suggest that irregularly flooded marshes of the A-P system exhibit patchy matrices of vegetation rather than zones. However, these studies were restricted to back-barrier island marshes of the Outer Banks and are not necessarily representative of interfluve or tributary shorezones. Bellis and Gaither (1985) produced maps and measured biomass of six marsh communities of Jacks Creek, a tributary to South Creek stemming from the Pamlico River estuary. While they offer no discussion of vegetation pattern, their map illustrates a mosaic of vegetation communities as well.

Brinson (1991b), however, identified three zones of brackish marsh along an apparent salinity gradient occupying a relic interfluve setting at Cedar Island National Wildlife Refuge. While *Juncus roemerianus* was the dominant plant in each zone, it decreased in abundance landward from the shoreline. This trend was coupled by a decrease in hydroperiod and a slight increase in marsh surface elevation. The seaward-most zone, Zone 1, consisted primarily of an expansive, near monotypic *J. roemerianus* marsh with a low storm levee just landward of narrow fringe of *Spartina alterniflora* at the shoreline. This zone remained inundated throughout much of the year. Zone 2 consisted of vegetation patches dominated by *Spartina patens* amongst a matrix of mixed marsh dominated by *J. roemerianus*. The landward-most zone, Zone 3, reflected more oligohaline conditions and thus consisted of a greater diversity of marsh vegetation. It was ultimately defined by the presence of *Morella cerifera* though *J. roemerianus* and *S. patens* were most abundant. Similarly, Brinson *et al.* (1985) suggest that intermittent inundation by brackish water caused an apparent gradient in structure and biomass along forested shorezones of Jacobs Creek and Jacks Creek, again tributaries to South Creek of the Pamlico River estuary. More recently, Poulter (2005) found that salinity and hydroperiod were inversely proportional to distance from shoreline in shorezones of the A-P system, which corresponded to zonation of vegetation. As a result, he organized species into marsh, transition, and forest communities.

In the Classification of Natural Communities of North Carolina, Third Approximation, Schafale and Weakley (1990) describe seven communities that are applicable to irregularly flooded shorezones: Brackish Marsh, Tidal Freshwater Marsh, Maritime Scrub Swamp, Maritime Scrub, Maritime Swamp Forest, Tidal Cypress-Gum Swamp, and Estuarine Fringe Loblolly Pine Forest. Collectively, these communities represent a continuum of vegetation types that may be found within the study area outlined in Chapter 1 (Figure 1-1).

While these studies combine to form a significant foundation of botanical and environmental knowledge of the region's shorezones, they either focus at local scales (*i.e.*, across shorezones) or at a very large regional scale in the case of Schafale and Weakley (1990). None investigate different shorezones along a salinity gradient such as that of the Neuse River estuary. Additionally, no literature specific to shorezone vegetation of the Neuse River estuary was found. Natural area inventories for Carteret (Fussell *et al.* 1983) and Craven (McDonald 1981) Counties identify individual sites associated with shorezones and stress their importance to the region but do not reflect vegetation patterns. In this chapter, shorezone plant communities of the Neuse River estuary and western Pamlico Sound are sampled at inner, middle, and outer estuary positions. Field data were arranged into a hierarchical classification and analyzed for patterns, both locally and regionally.

Methods

Three sampling areas representative of inner, middle, and outer estuary positions (*i.e.*, interstream divide units N1, S4, and S8 from Chapter 1) were selected to compare plant species composition and abundance, soil, and elevation amongst shorezone communities (Figure 2-1). The HGM wetland map (NCDENR 2003a) was used as a guide for establishing the number and location of transects. Three transects were established at outer and middle estuary settings stemming from shorelines mapped estuarine (Table 2-1). Six transects were established at the inner estuary setting, two stemming from shorelines mapped estuarine and four stemming from shorelines mapped riverine. Flat wetlands generally did not occupy shorelines; however they are noted in Table 2-1 where transects traversed more than one wetland type. Each transect is labeled I, M, O respective of the inner, middle or outer estuary sampling area at which it was sampled followed by a number (Figure 2-1). Specific transect locations within wetland types were determined by using aerial photographs and proximity to a public access road.

Transects were aligned perpendicular to the shorezone extending from the shoreline to its landward margin. At the shoreline, a Trimble GeoExplorer 3 global positioning system (GPS) was used to record the starting point of each transect. A sighting compass was then used to record the transect azimuth that was followed across the shorezone. Heading landward from the shoreline, a belt transect was used to assess plant communities that would be sampled upon return to the shoreline. Width of the belt transect was stratified by vegetation stratum: 1 m wide for the herbaceous stratum, 6 m wide for the shrub stratum, and 12 m wide for the tree stratum (Figure 2-2). The distance of community transitions (*i.e.*,

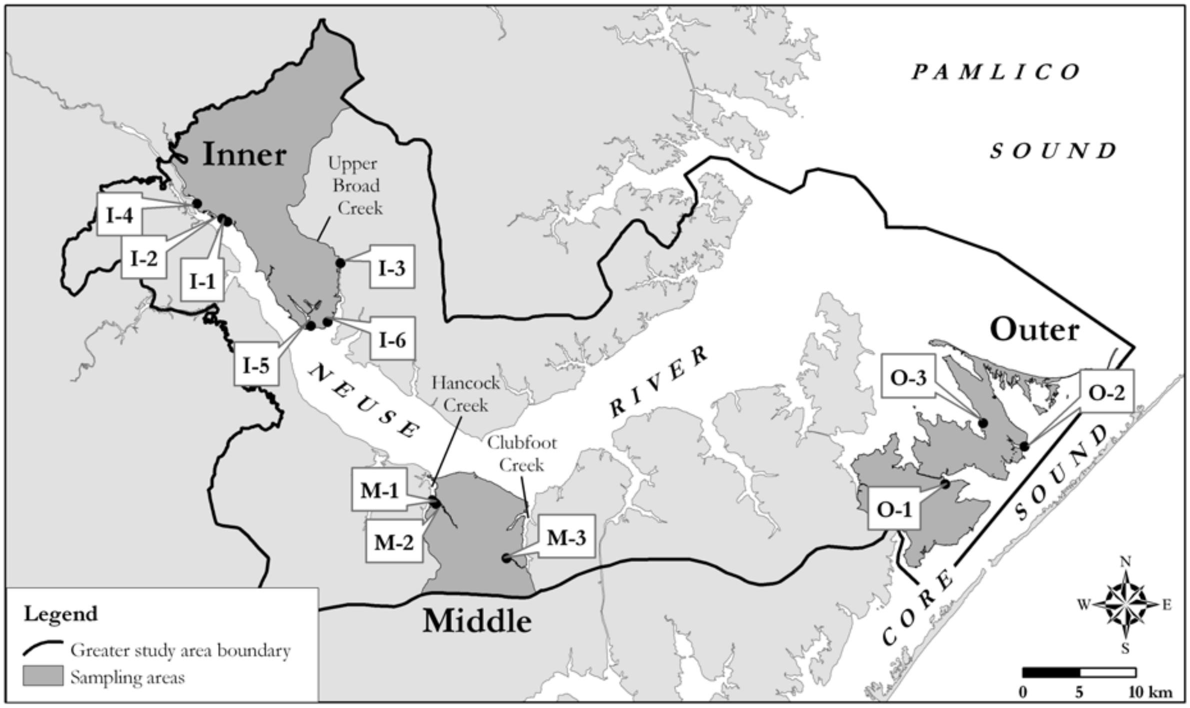


Figure 2-1. Inner, middle, and outer estuary sampling areas and location of transects.

Table 2-1. List of transects, the wetland type analyzed, geographic coordinates, azimuth and length of transect from shoreline to landward margin.

Transect	Wetland Type	Latitude	Longitude	Azimuth (°)	Length (m)
I-1	riverine	35°08'36.13"	-77°02'42.75"	30	98
I-2	riverine	35°08'44.63"	-77°03'22.44"	68	138
I-3	riverine/flat	35°06'30.65"	-76°56'10.60"	90	172
I-4	riverine	35°09'29.20"	-77°04'28.12"	140	93
I-5	estuarine/flat	35°03'32.62"	-76°57'59.12"	50	164
I-6	estuarine/flat	35°03'42.20"	-76°57'47.62"	310	189
M-1	estuarine	34°55'06.34"	-76°51'07.83"	180	19
M-2	estuarine	34°54'55.54"	-76°50'55.60"	280	100
M-3	estuarine/riverine	34°52'15.26"	-76°46'54.10"	170	101
O-1	estuarine/flat	34°55'17.65"	-76°21'21.93"	210	1216
O-2	estuarine/flat	34°56'58.91"	-76°16'42.41"	330	241
O-3	estuarine/flat	34°58'09.57"	-76°19'40.28"	70	831

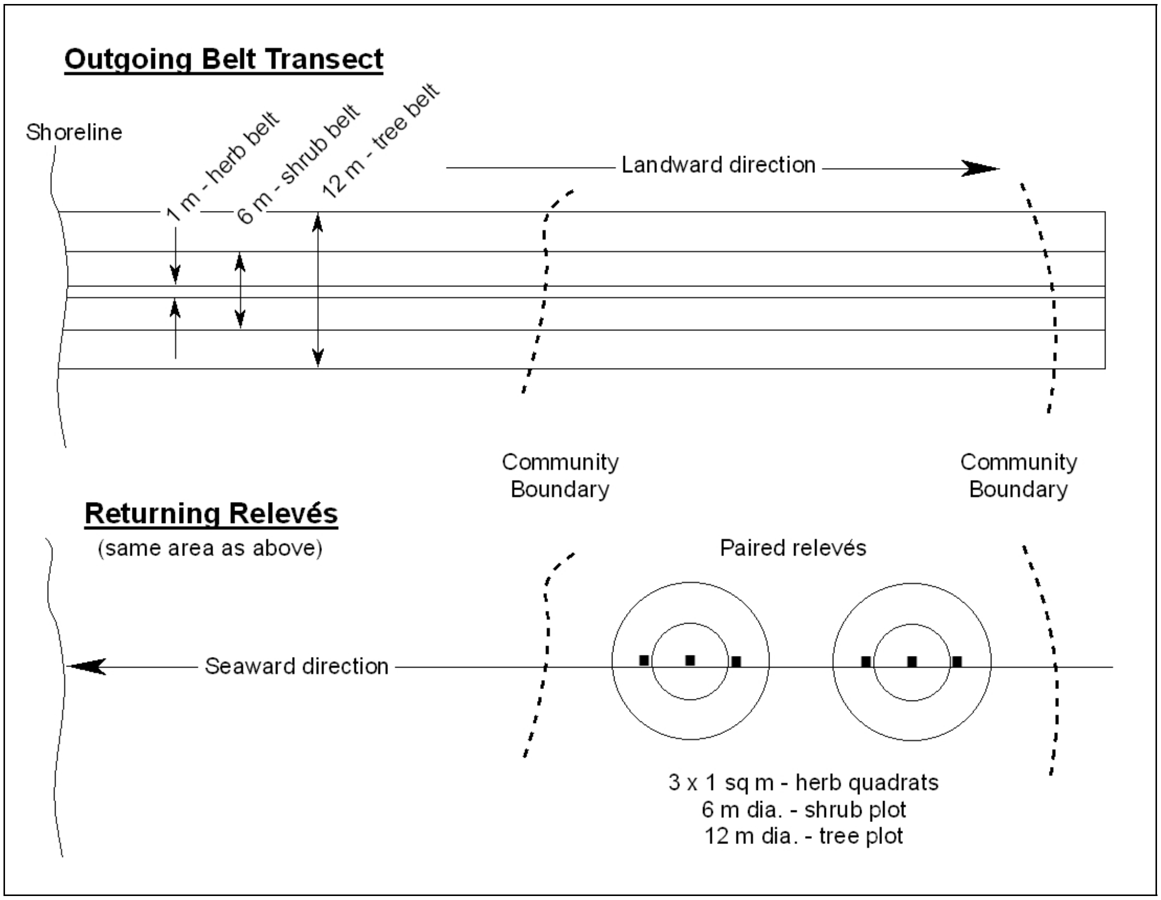


Figure 2-2. Belt transect and relevé sampling design. The belt transect was stratified by vegetation stratum: 1 m wide for the herbaceous stratum, 6 m wide for the shrub stratum, and 12 m wide for the tree stratum. Within each community, dominant species were noted within the 1, 6, and 12 m belts. Once the landward margin of shorezone (*e.g.*, a noticeable change in elevation or prevalence of upland plant species) was reached, two relevés were used to sample each community segment on return to the shoreline. Relevés were placed approximately 1/3 and 2/3 the way through each community in line with the transect. Relevés consisted of three 1 m^2 quadrates for the herbaceous stratum, one 6 m diameter plot for the shrub stratum, and for the tree stratum a measure of basal area and one 12 m dia. plot for stem density. An estimate of cumulative percent cover of the shrub and tree strata were recorded so as to convert density and importance values of the respective strata to percent cover.

boundaries) from the shoreline were measured using a hip chain. Within each community, dominant species were noted within the 1, 6, and 12 m belts.

Transects terminated at or just beyond the landward margin of shorezone (*e.g.*, a noticeable change in elevation and/or prevalence of upland plant species). On return to the shoreline, two relevés were sampled in each community. Relevés were located approximately 1/3 and 2/3 the way through each community along the transect. Relevés included three 1 m^2 quadrats for the herbaceous stratum, a 6 m diameter plot for the shrub stratum, and a 12 m diameter plot for the tree stratum. Where community segments were less than 24 m wide, one relevé was set at the mid-point of the community while the other was off-set perpendicular to the transect.

Herbaceous stratum quadrats were evenly spaced along the transect within the 12 m plot. Percent cover of herbaceous vegetation and woody plants <1 m tall were sampled using a modified Braun-Blanquet cover abundance scale. Woody plants >1 m tall but <10 cm diameter at breast height (dbh) were tallied in the shrub stratum plot. Relative density relative dominance were recorded for woody plants > 10 cm dbh (Muller-Dumbois and Ellenberg 1974). Relative density was measured within the 12 m diameter plot while relative dominance was measured using a foresters' basal area tree gage (10 factor, ft^2/ac). The two measures were added together to yield importance values for each species in the tree stratum. An estimate of total percent cover was recorded for both the shrub and tree strata separately. For each relevé the density of dead standing trees or shrubs (>1 m tall), stumps (<1 m tall), large and down woody debris (>10 cm diameter) were recorded. The presence of wrack and evidence of fire were noted within the 12 m plot.

Soil profiles were collected and analyzed between 0-30 cm and 30-60 cm from the soil surface or to refusal using a Macaulay peat sampler. Profiles were analyzed for peat texture (fibric, hemic, or sapric) or mineral content (clay, silt, or sand) by feel analysis (Thien 1979). Three samples were collected, two between 0-30 cm and one between 30-60 cm, and placed on ice until additional analyses could be performed in the laboratory. Peat depth was determined at each relevé generally by a transition from predominantly black sandy muck to a gleyed matrix of clay, silt, or sand below. The transition generally occurred a few centimeters above the point of refusal.

Soil samples were analyzed in the laboratory for bulk density, organic matter content as loss on ignition, and soil porewater salinity. Samples from 0-30 and 30-60 cm were oven dried at 85º C until constant weight for bulk density. Each sample was then ground to a homogenous mixture using a mortar and pestle. Subsamples of approximately 1-3 g were ashed in a muffle furnace at 500º C for 4 hr to yield loss on ignition. The additional sample collected between 0-30 cm was used to measure soil porewater salinity. That sample was homogenized and approximately a 50 mL subsample was placed into a centrifuge tube and centrifuged at 3000 rpm for 20 min. to extract pore water (Forbes and Dunton 2006). A Lieca refractometer was used to measure salinity of the supernatant.

Relative elevation was recorded at the center point of relevés along each transect using a Total Station® transit and telescoping stadia rod. Elevations are reported relative to the lowest elevation of each transect, generally at the shoreline. Each transect has its own datum; therefore, precise elevations cannot be compared between transects.

Analysis

Field data were transferred to a spreadsheet and the following adjustments were made. Percent cover of species for the three herbaceous stratum quadrats were averaged. Shrub stratum density counts and tree stratum importance values (Muller-Dumbois and Ellenberg 1974) were converted to percent cover of species for consistency with herb data. Conversion of the shrub and tree strata data to percent cover was calculated as the relative proportion of each species times the overall percent cover estimate of the respective stratum.

Paired relevés from each community segment along a transect were screened for similarity using the Ellenberg similarity index (Muller-Dumbois and Ellenberg 1974). If paired relevés exhibited >25% similarity, their data were averaged to represent one sample from that particular community assemblage. Where paired relevés demonstrated <25% similarity, a judgment was made as to whether low similarity was due to within segment heterogeneity or due to actual zonation that was overlooked in the field. In total, 8 out of 86 relevés were treated as individual community samples. The spreadsheet was then broken down into partial, or transect tables so as to compare samples across shorezones, between transects, and between inner, middle, and outer estuary sampling areas. Assumptions about the data were compared with the results of an unconstrained ordination procedure.

Ordination

An unconstrained ordination was performed with a matrix consisting of 47 samples by 35 of the most important species reflecting abundance of species as percent cover. Important species were determined by multiplying the maximum percent cover of a species by its number of occurrences. Species whose products' were >30 were retained for the matrix. Environmental data (*e.g.*, distance from shoreline, soil porewater salinity, elevation, etc.) and various categorical data were arranged into a secondary ordination matrix. A detrended correspondence analysis (DCA) (Hill and Gauch 1980) was performed with PC ORD® Version 5 (McCune and Mefford 2006) because it is most appropriate for exploring vegetation patterns along environmental gradients that exhibit high beta diversity (De'ath 1999). Parameters were set to rescale axes using a threshold of 0.0, number of segments was set to 26, and rare species were downweighted. Results were plotted on a two dimensional graphs with samples identified by cover type to illustrate the inherent pattern of the data.

Results and Discussion

Table 2-2 lists all plant species identified during sampling and the inner, middle, and outer estuary sampling areas at which each was observed. *Morella cerifera* was the most frequently encountered species of the shorezone occurring in 21 of 47 samples followed by *Juncus roemerianus* and *Acer rubrum* with approximately 17 and 15 occurrences, respectively.

In total, sixteen community types and five subtypes, were identified as follows: *Spartina alterniflora* fringe; *S. alterniflora/Juncus* marsh; *Juncus* marsh; *Spartina cynosuroides*/*Juncus* marsh; *S. cynosuroides* marsh; mixed marsh, subtypes levee and interior; *Cladium* marsh; *Cladium* scrub; *Cladium/Taxodium* scrub; *Morella* scrub, subtypes swamp, ghost forest, and margin; *Persea* forest; Mixed forest; *Carex/Baccharis*/*Taxodium* scrub; *Taxodium/Nyssa* swamp forest; *Pinus serotina* scrub; and *Pinus taeda* forest. Each community type is described below and arranged according to its respective cover type: low brackish marsh, high brackish marsh, oligohaline marsh, oligohaline marsh/scrub-shrub, scrub-shrub, and forest. Cover types are further arranged according to their respective hydrogeomorphic wetland classes: estuarine, riverine, flat or as wetlands of overlapping hydrogeomorphic constraints. Figure 2-3 illustrates the multi-level hierarchical arrangement of wetland types, cover types, community types, and synonymy with the natural communities described by Schafale and Weakley (1990).

<u>Estuarine wetlands</u>

Estuarine wetlands consist of low brackish marsh and high brackish marsh cover types. The two groups appear to occur at different elevations, the former lower than the

Table 2-2. List of plants observed in shorezones of the study area in order of occurrence out of a total of 47 samples. Plants observed within relevés denoted by X, plants observed outside of any relevés denoted by ‘p’. The species names follow the accepted nomenclature of the International Taxonomic Information System (ITIS) as of August 2008 unless otherwise noted. Taxonomic manuals used to identify vegetation within the study area included Weakley (2008) and Godfrey and Wooten (1979).

	Sampling areas			Total
Species	**Inner**	**Middle**	**Outer**	**occurrences**
Morella cerifera (L.) Small	X	X	X	21
Juncus roemerianus Scheele	X	X	X	17
Acer rubrum L.	X	X	X	15
Persea palustris (Raf.) Sarg.	X	X	X	13
Toxicodendron radicans (L.) Kuntze	X	X	X	12
Cladium mariscus (L.) Pohl ssp. *jamaicense* (Crantz) Kükenth.	X	X	X	10
Juniperus virginiana L.	X	X	X	10
Osmunda regalis L.	X	X	X	10
Spartina cynosuroides (L.) Roth	X	X		10
Baccharis halimifolia L.	X	X	X	9
Polygonum spp. L.	X	X	X	9
Solidago sempervirens L.	X	X	X	9
Nyssa biflora Walt.	X	X	X	8
Pinus taeda L.	X	X	X	8
Rubus spp. L.	X		X	8
Spartina patens (Ait.) Muhl.			X	8
Hibiscus moscheutos L.	X	X		7
Ipomoea sagittata Poir.	X	X	X	7
Iva frutescens L.	X	X	X	7
Mikania scandens (L.) Willd.	X	X	X	7
Distichlis spicata (L.) Greene			X	6
Liquidambar styraciflua L.	X	X	X	6
Taxodium distichum (L.) L.C. Rich	X	X		6
Fimbristylis castanea (Michx.) Vahl			X	5
Osmunda cinnamomea L.	X		X	5
Panicum virgatum L.	X	X	X	5
Rosa palustris Marsh.	X		X	5
Alternanthera philoxeroides (Mart.) Standl.	X			4
Eupatorium serotinum Michx.		X	X	4
Fraxinus carolinana P. Mill.	X		X	4
Hydrocotyle spp. L.	X	X		4
Juncus coriaceus Mack.	X	X	X	4
Kosteletzkya virginica (L.) K. Presl ex Gray	X		X	4
Polygonum arifolium L.	X			4
Smilax rotundifolia L.	X	X	X	4
Carex comosa Boott	X			3

Table 2 (continued).

Species	**Sampling areas**			**Total occurrences**
	Inner	**Middle**	**Outer**	
Cicuta maculata L.	X	X		3
Eleocharis spp. R. Br.	X		X	3
Hydrocotyle umbellata L.	X	X	X	3
Lyonia lucida (Lam.) K. Koch	X		X	3
Nyssa aquatica L.	X		X	3
Peltandra virginica (L.) Schott	X			3
Pontederia cordata L.	X			3
Ptilimnium capillaceum (Michx.) Raf.	X	X		3
Rumex spp. L.	X		X	3
Salix spp. L.	X		X	3
Smilax bona-nox L.		X	X	3
Spartina alterniflora Loisel.			X	3
Typha latifolia L.	X		X	3
Amaranthus cannabinus (L.) Sauer	X	X		2
Ampelopsis arborea (L.) Koehne	X		X	2
Berchemia scandens (Hill) K. Koch	X	X		2
Bignonia capreolata L.		X		2
Boehmeria cylindrica (L.) Sw.	X		X	2
Borrichia frutescens (L.) DC.			X	2
Carex spp. L.			X	2
Chasmanthium laxum (L.) Yates		X	X	2
Erechtites hieracifolia (L.) Raf. ex DC.	X		X	2
Ilex coriacea (Pursh) Chapman	X			2
Ilex vomitoria Ait.			X	2
Lonicera japonica Thunb.	X			2
Packera glabella (Poir) C. Jeffrey	X			2
Pinus serotina Michx.			X	2
Sagittaria latifolia Willd.	X			2
Samolus valerandi L.		X		2
Saururus cernuus L.	X	X		2
Sium suave Walter	X			2
Smilax spp. L.	X			2
Smilax laurifolia L.		X	X	2
Ulmus americana L.	X			2
Alnus Milspp. L.	X			1
Apios americana Medik.			X	1
Arundinaria gigantea (Walter) Muhl.	X			1
Bacopa monnieri (L.) Pennell			X	1
Carex glaucescens Elliot			X	1
Carex stricta Lam.	X			1
Carya tomentosa (Lam.) Nutt.		X		1
Caryophyllaceae spp.	X			1
Clethra alnifolia L.	X			1

Table 2 (concluded).

Species	Sampling areas: Inner	Middle	Outer	Total occurrences
Convolvulus spp. L.	X			1
Cyrilla racemiflora L.		X		1
Fraxinus spp. L.			X	1
Gaylussacia spp. Kunth			X	1
Gelsemium sempervirens (L.) W.T. Aiton			X	1
Hamamelis virginiana L.		X		1
Ilex opaca Ait.	X			1
Itea virginica L.	X			1
Lemna minor L.			X	1
Leucothoe axillaris (Lam.) D. Don			X	1
Liriodendron tulipifera L.			X	1
Lobelia cardinalis L.	X			1
Lythrum lineare L.		X		1
Parthenocissus quinquefolia (L.) Planch.			X	1
Phlox spp. L.	X			1
Pluchea odorata (L.) Cass.			X	1
Polygonum sagittatum L.	X			1
Pteridium aquilinum (L.) Kuhn	X			1
Quercus alba L.		X		1
Quercus laurifolia Michx.			X	1
Quercus nigra L.			X	1
Ranunculus spp. L.	X			1
Ruppia maritima L.		X		1
Salicornia depressa Standl.			X	1
Setaria parviflora (Poir.) Kerguélen			X	1
Typha angustifolia L.	X			1
Viburnum dentatum L.	X			1
Vitis spp. L.	X			1
Woodwardia virginica (L.) Sm.		X		1
Yucca filamentosa L.		X		1
Cuscuta gronovii Willd. ex J.A. Schultes			p	p
Schoenoplectus americanus (Pers.) Volk. ex Schinz & R. Keller			p	p
Schoenoplectus robustus (Pursh) M.T. Strong			p	p

Landscape scale - wetland type -	Shorezone scale - cover type -	Plant community scale - community type -	Schafale and Weakley (1990) synonymy
Estuarine wetlands	Low brackish marsh	*Spartina alterniflora* fringe *Spartina alterniflora /Juncus* marsh *Juncus* marsh *Spartina cynosuroides /Juncus* marsh	Brackish Marsh
	High brackish marsh	Mixed marsh (levee/interior)	Brackish Marsh
Transitional wetlands	Oligohaline marsh	*Spartina cynosuroides* marsh *Cladium* marsh	Tidal Freshwater Marsh
	Oligohaline marsh/scrub-shrub	*Cladium/Taxodium* scrub *Cladium* scrub	Tidal Freshwater Marsh
	Scrub-shrub	*Morella* scrub (margin)	Maritime Scrub
		Morella scrub (swamp/ghost forest)	no synonym
		Carex/Baccharis/Taxodium scrub	no synonym
	Forest	*Persea* forest	Maritime Scrub Swamp
Riverine wetlands	Forest	*Taxodium/Nyssa* swamp	Tidal Cypress-Gum Swamp
Flat wetlands	Scrub-shrub	*Pinus serotina* forest	no synonym
	Forest	Mixed forest	Maritime Swamp Forest
Upland (non-shorezone)	Forest	*Pinus teada* forest	Estuarine Fringe Loblolly PineForest

Figure 2-3. Hierarchical classification of shorezone wetland types, cover types, community types and synonymy with Schafale and Weakley (1990).

latter, as reflected in their names. The two cover types are often distinguishable on aerial photographs.

Low Brackish marsh

Low brackish marsh included four different community types that are described as follows. A *Spartina alterniflora* fringe community type commonly bordered the shoreline of the outer estuary (*e.g.*, transects O-1 and O-2; Appendix A). *S. alterniflora* was the only species present in this community that occupied a narrow area 1-3 m wide running parallel to the shoreline. Its elevation was lower or level with adjacent communities while soil porewater salinity ranged between 24 and 33. Soils were a silty muck with higher mineral content relative to interior shorezone communities. Subsurface peat depth ranged 160-200 cm below the marsh surface.

S. alterniflora/Juncus marsh was dominated by patches of *S. alterniflora* and *Juncus roemerianus*. Percent cover for this community was low because the sampled area was disturbed by fire 4 months prior to sampling. Soils consisted of fibric peat but were high in mineral content, primarily silt. Soil porewater salinity measured 30 while depth of peat measured 113 cm. This community was only observed in the outer estuary and adjacent to Core Sound, transect O-2. A unique feature within this community was the occurrence of presumable relic tidal creeks that have since filled with sediment.

Juncus marsh was present at each sampling area (*e.g.*, transects O-1, O-2, M-3, I-3, and I-5; Appendix A). This community was dominated by *J. roemerianus* with negligible cover by a few other species, mainly *Distichlis spicata* and *Kosteletzkya virginica*. Soils were relatively high in organic mater with fibric to hemic texture. Porewater salinity ranged between 6 and 20. Depth of peat measured 80-110 cm. *Juncus* marsh generally occupied the lowest elevations of the marsh and the soil surface was often inundated.

At middle and inner estuary sites, *Spartina cynosuroides* and *J. roemerianus* co-dominated dense stands along shorelines and into the interior marsh constituting the *S. cynosuroides/Juncus* marsh community type (*e.g.*, transects M-1, M-2, I-5, and I-6; Appendix A). A unique vegetation structure was present in these communities in that *S. cynosuroides* formed a canopy about 2.5 m high with an understory of *J. roemerianus* below 1.5 m height. Soils were highly organic and of relatively low elevation, excluding storm levees that where higher in elevation and consisted of layers of stratified peat and sand. Soil porewater salinity ranged between 6 and 13 and depth of peat measured 85-110 cm. Along some transects (*e.g.*, transects I-5 and I-6; Appendix A) this community extended over storm levees where soils exhibited higher mineral content, primarily sand. *I. frutescence* was often present on the storm levees in this community but was not dominant.

High brackish marshes

Mixed marsh was generally characterized by patches of *Spartina patens, D. spicata, Iva frutescence,* or *Fimbristylis castanea* and was observed only in the outer estuary. This community exhibited two subtypes related to its position within the shorezone, levee mixed marsh and interior mixed marsh. Levee mixed marsh occurred atop storm levees adjacent to the shoreline and was present at two transects (see transects O-2 and O-3; Appendix A). It was characterized by a raised soil surface between 19 and 28 cm higher than adjacent marsh surfaces and consisted of stratified layers of sand and fibric peat. Below the sandy surface layer, peat extended to depths of 170-230 cm. Soil porewater salinity ranged between 7 and 9. Interior mixed marsh was present along all three transects of the outer estuary sampling area, O-1, O-2 and O-3 (Appendix A). Vegetation was similar to levee mixed marsh; however its position was generally landward of *Juncus* marsh at considerable distance from the shoreline. Interior mixed marsh had greater species richness with *Panicum virgatum, J. roemerianus*, *Morella cerifera,* and *Baccharis halimifolia* also demonstrating notable cover. Relative elevation of interior mixed marsh was higher than adjacent seaward marsh communities by 16 cm. Soils ranged from highly fibric peat to sapric sandy peat. Porewater salinity ranged 9-27. Mixed marshes were included as high brackish marsh communities, rather than low brackish marsh communities because they consistently occurred at slightly higher elevations but were also dominated by vegetation known to inhabit high marsh areas of regularly flooded salt marshes.

The communities identified as either high brackish marsh or low brackish marsh above can be regarded as subtypes, or variants of Brackish Marsh described by Schafale and Weakly (1990) (Figure 2-3). Some contradictions to their assessment lower and higher zones. For example, *Spartina patens* was never observed in the lower elevations of sampling areas as they suggested, but rather on the higher elevations of levee and interior mixed marshes. They also suggested that *K. virginica* and *Hibiscus moscheutos* were characteristic of higher elevations. *K. virginica*, while rare during sampling, was almost always associated *Juncus* marsh, which occupied the lowest elevations. The only areas where higher elevations correspond with differences in species composition of brackish marshes were at the outer estuary sampling areas. Overall, these data concur with Schafale and Weakley (1990) that *J. roemerianus* is the most abundant species occupying irregularly flooded brackish marshes in this region.

Wetlands of overlapping hydrogeomorphic settings

Whether the shorezone concept is considered locally or regionally, there is a continuum of vegetation that occurs between hydrogeomorphic settings. Conditions that are normally attributed to estuarine wetlands overlap with those of riverine or flat wetlands somewhere between the two settings. Oligohaline marsh, Oligohaline marsh/scrub-shrub, and some scrub-shrub and forest cover types exhibit overlapping characteristics.

Oligohaline marsh

S. cynosuroides marsh occurred along one inner estuary transect, I-1 (Appendix A). It was dominated by *S. cynosuroides* with minimal cover by *Typha latifolia* and positioned adjacent to the shoreline of the Neuse River behind a relic stand of *Taxodium distichum* approximately 20-30 m off-shore. Soils were highly organic and elevation was only slightly higher than landward *Morella* scrub communities. Considerable hummock and hollow microtopography was present. Depth of peat measured 265 cm below the surface. Porewater salinity was low, between 0 and 1.

Cladium marsh was present at all three sampling areas (*e.g.*, transects O-1, M-2, M-3, and I-3; Appendix A) but was not consistently present along all transects. It generally consisted of dense, near monotypic stands of *Cladium mariscus. Hibiscus moscheutos* and *Ipomoea sagittata* also exhibited significant, though inconsistent, cover in this community. Soils were highly organic with peat extending between 100 and 200 cm below the surface. Soil porewater salinity ranged between 2 and 10 and relative elevation was generally higher than seaward communities.

Cladium and *S. cynosuroides* marsh community types closely resemble Tidal Freshwater Marsh described by Schafale and Weakly (1990). However, the term "oligohaline" in lieu of "freshwater" seemed more appropriate as soil porewater salinity within these communities regularly exceeded 1.

Oligohaline marsh/scrub-shrub

Woody vegetation regularly shared cover with *C. mariscus* toward the interior of shorezones. The *Cladium* scrub community was dominated by either *B. halimifolia* or *M. cerifera* in the shrub stratum and by *C. mariscus*, and *S. cynosuroides* in the herbaceous stratum (*e.g.*, transects I-3 and I-6; Appendix A). The *Cladium/Taxodium* scrub community occurred along transect M-3 (Appendix A) where *C. mariscus* appears to have invaded the understory of a mature *Taxodium distichum* stand. Soils in both communities were highly organic and depth of peat ranged 38-200 cm below the surface. Soil porewater salinity ranged between 3 and 10 and relative elevation was higher than seaward communities.

Regardless of the ubiquity of *C. mariscus* between Oligohaline marsh and Oligohaline marsh/scrub-shrub, the two are distinguished here because they appear to illustrate a pattern of zonation in that the latter generally occurs landward of the former. However, *Cladium* marsh is very possibly an initial community stage that eventually succeeds to *Cladium* scrub and potentially into more landward forest communities. Their different positions are presumably a result of varying salt stress and disturbance regimes. Schafale and Weakley (1990) avoided classifying such transitional plant communities but the oligohaline marsh/scrub-shrub communities are most likely related to their Tidal Freshwater Marsh description.

Scrub-shrub

The *Morella* scrub community type was observed along 9 of the12 transects. Because *M. cerifera* was rather ubiquitous throughout scrub-shrub and forest communities, soil, elevation and the abundance of dead standing trees were used to help distinguish 3 subtypes: swamp, ghost forest, and margin. *Morella* scrub swamp often included *Persea palustris*, *Acer rubrum, B. halimifolia, Juniperus virginiana, Rosa palustris,* and *Osmunda regalis* (*e.g.*, transects O-1, I-1, I-2, I-3, I-5, and I-6; Appendix A). Soils were highly organic, fibric to sapric in texture, and depth of peat measured 78-300 cm. Footing was poor with hummock and hollow microtopography. Soil porewater salinity ranged 0-6. Elevations within the *Morella* scrub swamp subtypes were not completed due to interference by vegetation. The ghost forest subtype is comparable to the swamp subtype but was distinguished because of its abundance of dead standing trees (*e.g.*, O-1; Appendix A). It was clear that a forest community had recently collapsed at this location. *Morella* scrub margin was situated at the upland/wetland boundary or landward margin of shorezone along transects O-2 and M-1 (Appendix A). While *M. cerifera* dominated, *P. serotina* and *N. biflora* were present but in low abundance. Key distinguishing environmental features of this subtype were non-hydric mineral soil and its elevation 47 cm above the lowest point of the transect. Soil porewater salinity was near zero for both occurrences. Also of interest, the *Morella* scrub margin subtype along transect M-1 lacked litter and an organic soil horizon. Evidence of landward wrack lines suggested that fluctuating water levels in the estuary were responsible for scouring organic matter from the soil surface. Successive wrack lines measured 1.16, 1.51, and 2.51 m above the M-1 datum along the steep landward slope.

Morella scrub margin appears synonymous with Maritime Scrub described by Schafale and Weakley (1990). However, *Morella* scrub swamp and ghost forest lacked a specific match with any of the communities described by Schafale and Weakley (1990); though they bore resemblance to *Persea* forest (see description of *Persea* forest below). The persistence of *Morella* scrub swamp throughout shorezones of the estuary may be an indicator of repeated salt stress.

Carex/Baccharis/Taxodium scrub occurred along only one transect, I-2. This community was separated from the shoreline by a 1 m tall x 3 m wide unvegetated storm levee. Here, *Carex comosa* dominated the herbaceous stratum of a relatively open canopy of *T. distichum*. *B. halimifolia* and *Rosa palustris* dominated the shrub stratum but did not form a dense thicket. Soils were sapric near the surface. Depth of peat measured 285 cm. Soil porewater salinity measured 2. Schafale and Weakley (1990) did not recognize a community synonymous with the *Carex/Baccharis/Taxodium* scrub. The presence of mature *T. distichum* trees, which are tolerant of salinity levels up to 10 (Conner *et al.* 1997), combined with its inner estuary position along the Neuse River, suggests it is a relic of the *Taxodium/Nyssa* swamp forest described below. It has likely resulted from repeated salt stress and disturbance (*e.g.*, windthrow). Signs of fire were not evident.

Forest

Persea forest occurred along only one transect in the middle estuary sampling area, transect M-2 (Appendix A). *Persea palustris* was the dominant tree species followed by *Acer rubrum and Juniperus virginiana*. *M. cerifera* dominated the shrub stratum while *O. regalis* and *Saururus cernuus* were the most abundant species in the herb stratum. *Persea* forest was situated in a narrow valley-like topographic feature partially filled with accumulated organic matter. Soils were fibric near the surface and extended to a depth of 300 cm. In an adjacent similar geomorphic setting at the confluence of Hancock Creek and Cahooque Creek, depth of peat measured 635 cm. Soil porewater salinity measured 2. *Persea* forest aligns with Maritime Scrub Swamp (Schafale and Weakley 1990), which is known only to occur in interdune swales at Buxton Woods and Nags Head Woods on the Outer Banks. Its presence here suggests a broader range extending to at least the middle estuary of the Neuse River. Additionally, *P. palustris* was consistently present in either shrub or tree stratum of *Morella* scrub swamp though it never dominated. This may suggest that *Morella* scrub swamp is an early successional stage of the *Persea* forest/Maritime Scrub Swamp community.

Flat wetlands

Flat wetlands are those wetlands that occur where shorezone occupies either interstream flat or paleo-braidplain flat geomorphic settings. They include scrub-shrub and forest cover types.

Scrub-shrub

Pinus serotina scrub was observed only at the outer estuary setting at the landward margin of transect O-3 (Appendix A). It was dominated by *P. serotina*, *Persea palustris,* and *Liquidambar styraciflua*. *Osmunda regalis, Carex* spp. *Eupatorium serotina,* and *S. patens* dominated the herb stratum. Soils were sandy with low organic matter while porewater salinity measured 3. Relative elevation was >50 cm above the transect datum. Its high elevation and species composition suggest the boundary between adjacent mixed marsh and itself represents the landward margin of shorezone. *P. serotina* scrub did not bear resemblance to any of the applicable communities described by Schafale and Weakley (1990).

Forest

Mixed forest typically occurred at or near the landward margin of shorezone (*e.g.,* transects O-1, I-2, I-3, and I-6; Appendix A). While relatively heterogeneous in species composition, it was always dominated by two or more of the following: *Nyssa biflora, Liquidambar styraciflua, Acer rubrum,* and *Pinus taeda*. *A. rubrum* and *P. palustris* were the only two constants of the tree stratum. *P. palustris* and *M. cerifera* were constant in the shrub stratum although the latter was dominant. Herbaceous vegetation was relatively inconsistent between transects. Soils ranged from fibric peat to black mucky sand and porewater salinity ranged between 0 and 9. Elevation data was incomplete for this community type because vegetation obstructed surveying. The mixed forest community described here is comparable to Maritime Swamp Forest described by Schafale and Weakley (1990). While they only report occurrences of the community along the Outer Banks, these data suggest a considerably larger range extending to the inner estuary.

Riverine wetlands

Riverine wetlands occupy upstream migrating shorezones of antecedent floodplains now hydrologically influenced by sea level. They are occupied by the forest cover type.

Forest

Taxodium/Nyssa swamp was observed only at the middle and inner estuary sampling areas, (*e.g.*, transect M-3 and I-4; Appendix A). While *T. distichum, Nyssa aquatica, N. biflora, Fraxinus carolinana, A. rubrum, Pinus taeda,* and *M. cerifera* were inconsistently dominant in the tree stratum, *T. distichum* and *N. biflora* were the two constants. Shrub and herbaceous strata were relatively heterogeneous in terms of species composition. Soils were fibric to sapric while porewater salinity ranged between 0 at the inner estuary transect to as high as 8 at the middle estuary transect. *Taxodium/Nyssa* swamp is compositionally comparable to Tidal Cypress-Gum Swamp identified by Schafale and Weakley (1990).

<u>*Upland non-shorezone forest*</u>

Pinus taeda forest occurred along one transect in the middle estuary (*e.g.*, transect M-1; Appendix A). *P. taeda* was the dominant species with *N. biflora* and *Liriodendron tulipifera* contributing to the tree canopy as well. *Cyrilla racemiflora* and *M. cerifera* dominated the shrub stratum. The herbaceous stratum was relatively sparse with no real dominants. Soils were non-hydric sandy loam with low organic matter content. Pore water salinity measured 0. *P. taeda* forest is not considered part of the shorezone due to its high elevation and steep landward slope.

<u>*Ordination*</u>

The DCA ordination reflects a continuum of vegetation typical of Neuse River and western Pamlico Sound shorezones (Appendix B, Figure B-1). However, a pattern of zonation is more apparent when samples are identified by their respective cover type (Figure 2-4). The high eigenvalue (0.945) determined for axis 1 reflects very high beta diversity between samples at opposite ends of the axis. An after-the-fact evaluation of the quality of the data reduction suggests only 14% ($r^2 = 0.147$) of the variation in the reduced space is represented by axis 1 (Appendix B, Table B-1). Nonetheless, strong correlations were observed between environmental variables and the DCA axes. Species richness demonstrated the strongest correlation with axis 1 ($r = -0.813$) (Appendix B, Figure B-4) followed by soil porewater salinity ($r = 0.731$) (Appendix B, Figure B-3). Forest communities appear to the left of the diagram. They exhibit the greatest species richness, least beta diversity between samples, and lowest soil porewater salinities. Low brackish marshes appear to the right of the diagram. In contrast, they exhibit the lowest species richness, greatest beta diversity, and highest soil porewater salinities.

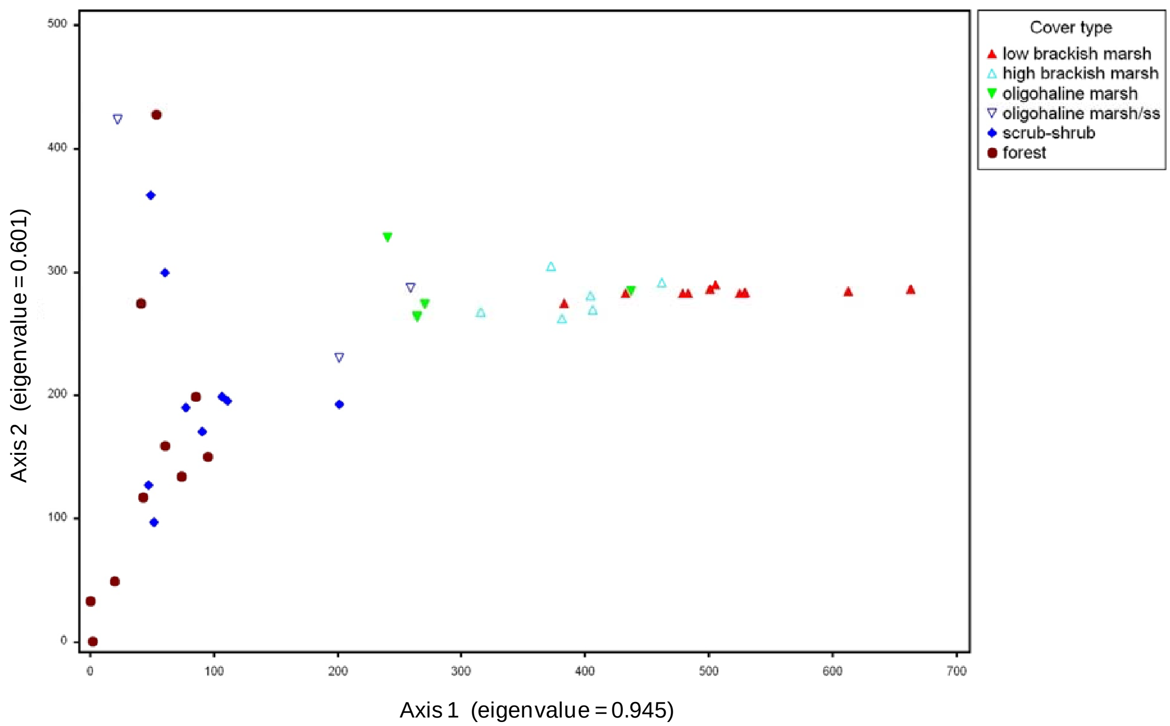


Figure 2-4. Detrended correspondence analysis ordination labeled according to cover type. Low brackish marsh samples are to the right. From left to right, samples diverge along axis 2 as they grade into high brackish marsh followed by oligohaline marsh, oligohaline marsh/scrub-shrub, scrub-shrub and forest along axis 1.

Forest communities located at the left side of the diagram appear to diverge toward two extremes along axis 2 (eigenvalue = 0.601): riverine wetlands (*i.e.*, *Taxodium/Nyssa* swamp) at the top and flat wetlands (*i.e.*, mixed forests) toward the bottom (Figure 2-5). While the r^2 value for Axis 2 is very low (-0.014) (Appendix B, Table B-1), which purportedly reflects a low percentage of the variance explained by the axis (McCune and Grace 2002), distance of community from shoreline (dist-n) exhibited a reasonably strong correlation with DCA axis 2 (r = -0.708) (Appendix B, Figure B-5). This finding is consistent with that of Chapter 1 in that forested flat wetlands tended not to occupy the shoreline of outer estuary shorezones because of the high salinity brackish waters, whereas forested riverine wetlands were more prevalent at or near the shoreline of inner estuary shorezones because of the lower salinities there. Axis 1 is therefore best explained by a salinity gradient while geomorphic settings appear to represent at least some of the variation along axis 2. A species plot of the DCA ordination can be seen in Appendix B, Figure B-2.

Local and regional patterns

Various patterns of vegetation were observed at the plant community scale. Studies of shorezones in the A-P system have suggested that its irregularly flooded marshes exhibit mosaic patterns rather than zonation. However, this study, among others (Brinson 1991b, Poulter 2005), suggests that patterns of zonation are apparent across these shorezones at both local (*e.g.*, from shoreline to landward margin) and regional (*e.g.*, from inner to outer estuary) scales. The most influential factors contributing to zonation are salinity and hydroperiod. The mosaic pattern undeniably exists; however, it occurs among the zonation of communities and is generally the result of wrack deposition (Knowles 1989).

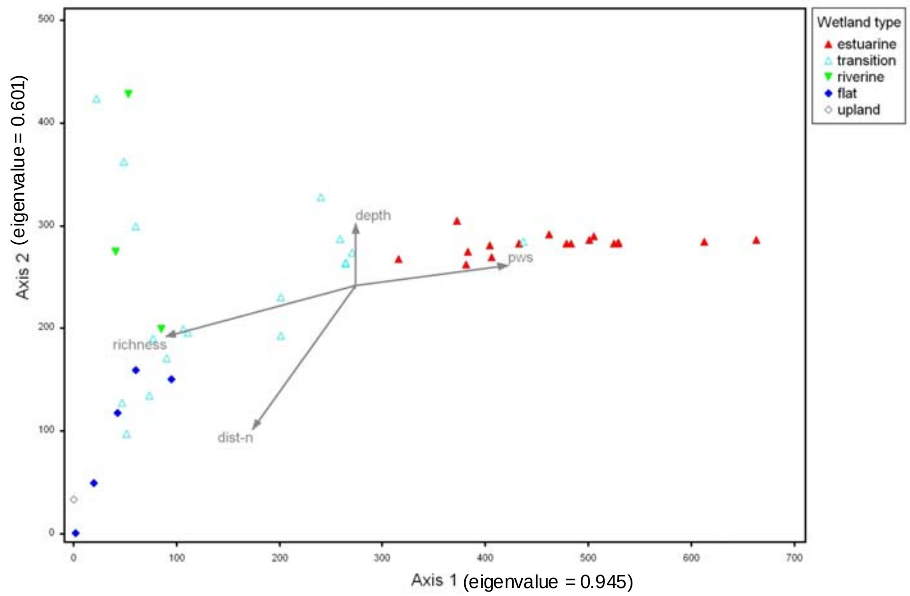


Figure 2-5. Detrended correspondence analysis ordination biplot labeled according to hydrogeomorphic wetland type (NCDENR 2003a). Length of arrows reflect the strength of the relationship with environmental variables, soil porewater salinity (pws), distance of community from shoreline (dist-n), species richness (richness), and depth of peat (depth). Samples are mostly estuarine toward the right of axis 1 but grade into either riverine (top) or flat (bottom) along axis 2 toward the left.

Local patterns

Peat depth consistently decreased from the shoreline to the landward margin at each estuary position (Figure 2-6). Communities adjacent to the shoreline exhibited lower soil organic matter content between 0-30 cm than did those of the interior (Figure 2-7). Subsurface sediments (30-60 cm) of communities adjacent to the shoreline were on average higher in organic matter (Table 2-3) suggesting that the mineral sediment above is allochthonous, and thus deposited during inundation (Craft 1993). Percent organic matter generally increased toward the interior of shorezone but decreased again at or near the landward margin, and often abruptly (Figure 2-7). Transect O-3 is the only example where mineral content increased gradually (field observation) through the high brackish marsh community approaching the landward margin. It traverses an area where landward slope is negligible enough that shorezone is not vertically impeded. This particular area therefore represents an excellent example of where shorezone is actively migrating over a flat. Transect O-1 and O-2 exhibit more abrupt transitions between organic and mineral soil because their landward margins coincide with paleo-shorelines (Mixon and Pilkey 1976), and thus are actually stalling in terms of landward migration. The remainder of middle and inner estuary transects all exhibited relatively abrupt organic to mineral soil transitions because they traverse shorezones in river valleys.

Inner estuary shorezones -Twice as many transects were established at the inner estuary sampling area than at middle and outer estuary sampling areas because it was comprised of both estuarine and riverine wetland shorelines (NCDENR 2003a). *S. cynosuroides*/*Juncus* marshes appeared to represent the estuarine wetlands and were restricted to the southeastern most portion of the inner estuary sampling area. These

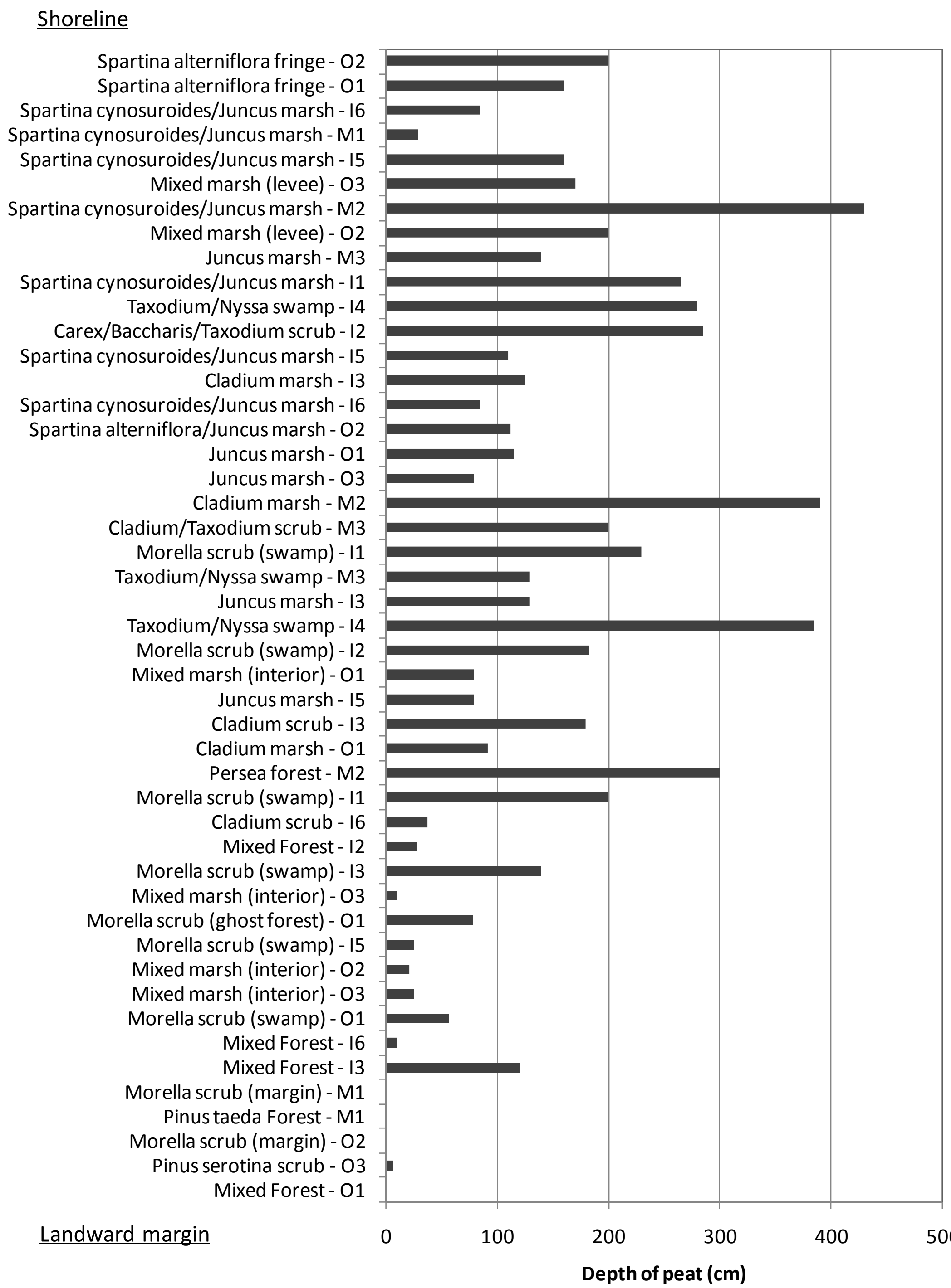


Figure 2-6. Depth of peat in centimeters of all samples. Samples are sorted by normalized distance from shoreline and labeled according their respective community type and transect. Samples closet to the shoreline are at the top of the chart, while those closest to the landward margin are at the bottom.

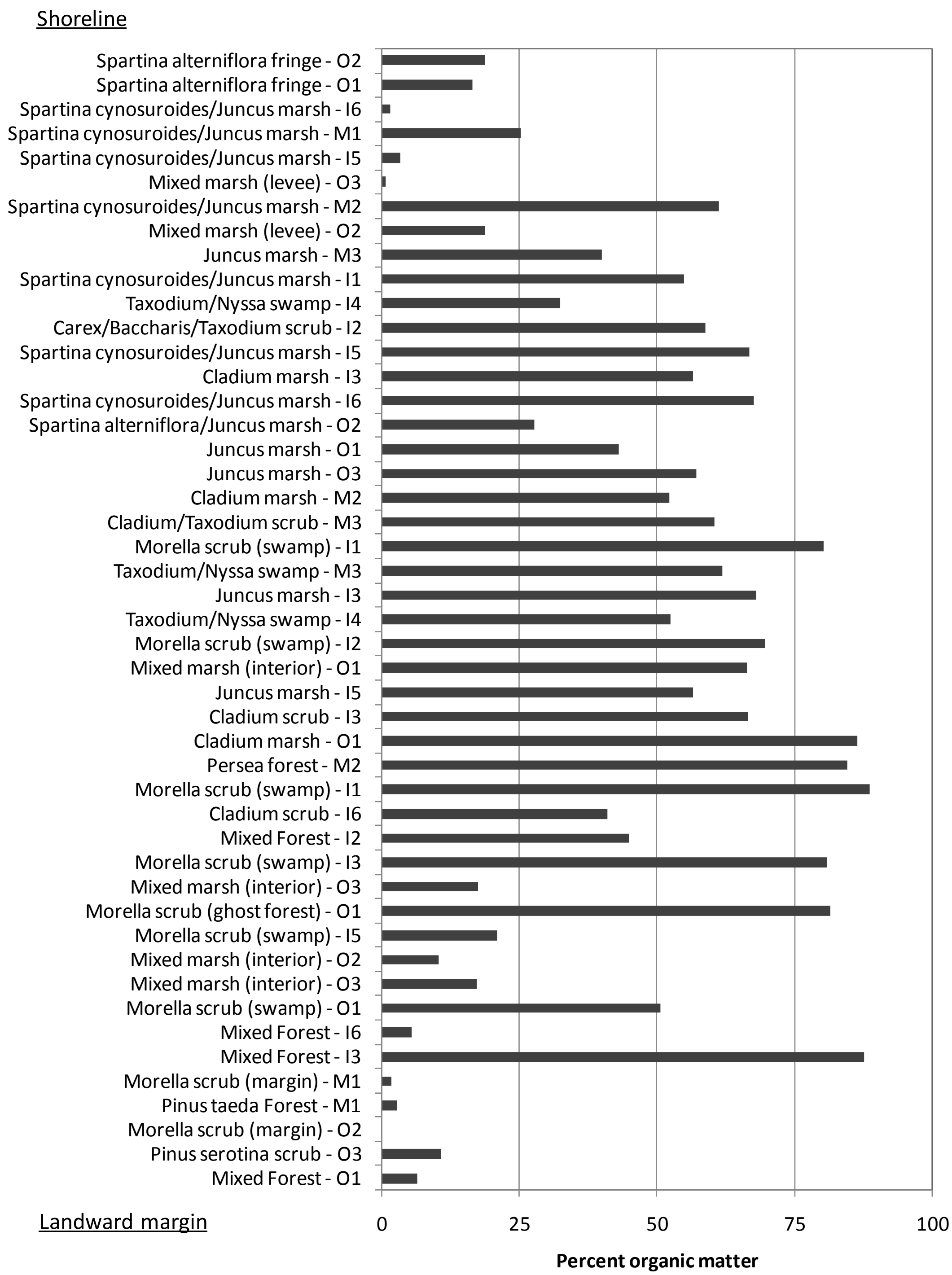


Figure 2-7. Percent organic matter of surface soil (0-30 cm) of all samples. Samples are sorted by normalized distance from shoreline and labeled according their respective community type and transect. Samples closet to the shoreline are at the top of the chart, while those closest to the landward margin are at the bottom. Organic matter was highest toward the interior of the shorezone.

Table 2-3. Average percent organic matter measured as loss on ignition of surface (0-30 cm) and subsurface (30-60 cm) soil samples from the first 12 samples in order of normalized distance from shoreline.

Community type	Transect	Distance from shoreline (m)	Percent organic matter	
			Surface	Subsurface
Spartina alterniflora fringe	O2	1	18.8	29.6
Spartina alterniflora fringe	O1	1	16.5	18.8
Spartina cynosuroides/Juncus marsh	I6	3	1.7	29.5
Spartina cynosuroides/Juncus marsh	M1	3	25.4	6.1
Spartina cynosuroides/Juncus marsh	I5	4	3.5	21.7
Mixed marsh (levee)	O3	6	0.9	0.0
Spartina cynosuroides/Juncus marsh	M2	7	61.1	69.7
Mixed marsh (levee)	O2	7	18.8	29.6
Juncus marsh	M3	11	39.9	19.1
Spartina cynosuroides/Juncus marsh	I1	19	55.0	72.1
Taxodium/Nyssa swamp	I4	21	32.5	48.2
Carex/Baccharis/Taxodium scrub	I2	28	58.9	71.1
		Avg.	27.7	34.6

marshes tended to grade into mixed forest or *Morella* scrub communities that occupied the flat wetlands of the paleo-braidplain. *Cladium* marsh or *S. cynosuroides* marshes were primarily associated with riverine wetland shorezones and occurred further upstream along either the Neuse River or Upper Broad Creek. They tended to grade laterally from the shoreline into mixed forest or *Morella* scrub communities as well. However, using communities occupying the shoreline of multiple transects (*e.g.*, I-1, I-3, I-2, and I-4, in that respective order), it can be inferred that those marshes grade in an upstream direction into *Carex/Baccharis/Taxodium* scrub and on into *Taxodium/Nyssa* forest of the Neuse River and Upper Broad Creek floodplain shorezones.

Reasonably wide shorezones were observed at the inner estuary sampling area, ranging between 94 and 324 m wide. Zonation of communities was least apparent here, limited mostly to vegetation structure (*e.g.*, marsh, scrub-shrub, and forest). Elevation did not appear to affect the distribution of *S. cynosuroides/Juncus* marsh as it occupied both storm levees and low brackish marsh settings of two transects at the southeastern most positions of the inner estuary. However, in the one location where *Juncus* marsh prevailed (Transect I-6), it exhibited the lowest elevation along the transect and was inundated at the time of sampling.

C. mariscus and *S. cynosuroides* appear to have similar tolerances for salinity but, surprisingly, they rarely co-occurred or dominated community types of the same shorezones. *S. cynosuroides* appeared to be restricted to shorezones of the Neuse River, while *C. mariscus* dominated shorezones of Upper Broad Creak, a blackwater tributary. This disparity may be attributable to water chemistry or wave energy as *C. mariscus* seemed to be associated only with other blackwater tributaries and dominated only shorezones that were not exposed to considerable fetch.

Middle estuary shorezones - Presently, sea level does not intersect middle estuary geomorphic settings in a way that promotes extensive shorezones (see hypsographic profile, Chapter 1). Here, shorezones are restricted only to valleys with steep lateral slopes deep inside tributaries to the Neuse River estuary. As a result, shorezones were relatively narrow, ranging between 7 and 136 m wide. *Juncus* marsh is considerably reduced, occupying the seaward most portion of only one transect. *S. cynosuroides/Juncus* marsh occupied the shorelines of the remaining two transects. *Cladium* marsh and *Cladium/Taxodium* scrub occupied intermediate positions between the aforementioned marshes and landward forests along two transects. *Morella* scrub, *Taxodium/Nyssa* swamp forest and *Persea* forest occupied the remainder of shorezone to the landward margin. The landward margin was always defined by an abrupt increase in landward slope. All shorezones were mapped estuarine wetland (NCDENR 2003a) and restricted to the inner most portions of tributaries.

Outer estuary shorezones - The low position of interstream divide flats in the outer estuary is responsible for the extensive shorezones (Chapter 1). These shorezones measured between 219 and 1214 m wide, nearly an order of magnitude greater than middle estuary shorezones. The majority of these shorezones are mapped estuarine wetland with flat wetlands toward the landward margin (NCDENR 2003a).

Zonation of plant communities was most apparent in outer estuary shorezones. The typical pattern began with *S. alterniflora* fringe or levee mixed marsh that paralleled the shoreline. To the landward side of these communities, *Juncus* marsh dominated expansive areas of low elevation that were generally inundated. Only toward shorelines of Core Sound did *J. roemerianus* share dominance with *S. alterniflora* (*e.g.*, transect O-2; Appendix A). Continuing landward, interior mixed marsh developed at a slightly higher elevation and shrubby vegetation became more prevalent, though not dominant. *Cladium* marsh persisted only in the presence of an apparent ground water source (*e.g.*, transect O-1; Appendix A). *Morella* scrub swamp or ghost forest occupied the area between *Cladium* marsh and the landward margin of shorezone. The landward margin appeared to be elevated approximately 40 to 50 cm above the lowest elevations of marsh. Mixed forest and *P. serotina* scrub communities occurred above this elevation on flat wetlands not considered to be part of the shorezone.

Levee and interior mixed marsh communities occur at very different positions relative to the shoreline, yet exhibit similar species composition. Additionally, both community subtypes exhibit different soils (*i.e.*, sand vs. peat) and are subject to different disturbance regimes, particularly related to wave energy. Related species composition may be a response to their higher elevations or lower soil porewater salinities relative to adjacent communities or a combination of the two. This finding is contrary to the concept that vegetation zonation is a factor of distance from shoreline as discussed by Poulter (2005). The two most prevalent species of mixed marsh are *S. patens* and *D. spicata*, both colonizers of areas disturbed by wrack deposition that opens the otherwise *J. roemerianus* canopy (Knowles 1989).

Spaur and Snyder (1999) found that *S. patens* generally occurred in areas where depth of peat measured approximately 40 cm. This study found no relationship between peat depth and vegetation type nor does this author believe one exists. The position of *S. patens* in the shorezone is more likely attributed to soil salinity, hydroperiod, or disturbance regime, all of which may covary with distance from shoreline (Knowles 1989, Christian *et al.* 1990, Poulter 2005).

Transects O-2 and O-3 burned during the winter prior to sampling. At transect O-2, fire did not have a uniform impact because patches of *J. roemerianus* remained unburned. Where the fire had burned *J. roemerianus* marsh, it exhibited considerably less cover than unburned areas. Additionally, the shrubs *I. frutescence* and *M. cerifera* exhibited fire resiliency. While the aboveground biomass was charred and dead, both species were sprouting from bases of their stems.

Regional patterns

Regional patterns in vegetation are best explained in Table 2-4 where community types are arranged by sampling area, and thus reflect the space-for-time framework outline in Chapter 1. *Juncus* marsh communities are present throughout the estuary while *S. alterniflora* fringe, *S. alterniflora/Juncus* marsh, and interior and levee mixed marsh are restricted to the outer estuary (Table 2-4). And while *Juncus* marsh was present at each position, it was most extensive in the outer estuary occupying zones >300 m wide. These communities are therefore characteristic of the late over-flat migration stage and the terminal non-migration stage, both of which coincide with higher salinities in the outer estuary.

Toward the middle and inner estuary, *J. roemerianus* generally shared its distribution fairly evenly with *S. cynosuroides* wherever it occurred. Marshes dominated entirely by *S. cynosuroides* appeared restricted to the very inner portions of the estuary primarily fringing shorezones of the Neuse River as opposed to its tributaries. While *S. cynosuroides* was not observed during sampling in the outer estuary (Table 2-4), but is known to occur there (Brinson *et al.* 1991b). *Cladium* marsh also occurred at all three positions of the estuary but

Table 2-4. Comparison of community and cover types with spatio-temporal stages identified in Chapter 1. Early, intermediate, and late stages are aligned with community types. Field data from Brinson *et al.* (1991b) were used to apply community type designations to terminal – non migration stage.

Cover type / Community type	- early - upstream migration (inner estuary)	- intermediate - non-migration (middle estuary)	- late - over-flat migration (outer estuary)	- terminal - non-migration (outer estuary)
Forest				
Taxodium/Nyssa swamp	X	X		
Persea forest		X		
P. taeda forest		X		
Mixed forest	X		X	
P. serotina scrub			X	
Scrub-shrub				
Carex/Baccharis/Taxodium scrub	X			
Morella scrub (margin)		X	X	
Morella scrub (swamp/ghost forest)	X	X	X	X
Oligohaline marsh/scrub-shrub				
Cladium/Taxodium scrub	X	X		
Cladium scrub	X	X	X	X
Oligohaline marsh				
S. cynosuroides marsh	X			
Cladium marsh	X	X	X	
High brackish marsh				
Mixed marsh (levee/interior)			X	X
Low brackish marsh				
S. cynosuroides /Juncus marsh	X	X		
Juncus marsh		X	X	X
S. alterniflora /Juncus marsh			X	X
S. alterniflora fringe			X	X

it was only found landward of *Juncus* marsh, interior mixed marsh, and *S. cynosuroides/Juncus* marsh at the middle and outer estuary sampling areas (Table 2-4). It was never present at the shoreline and only occupied large areas where there was an assumed fresh groundwater supply. Toward the inner estuary, *Cladium* marsh occupied the shoreline and major portions of the shorezone of Upper Broad Creek, a tributary to the Neuse River (*e.g.*, transect I-3; Appendix A). *S. cynosuroides* and *Cladium* marshes are therefore representative of the trailing edge of shorezone where upstream migration is occurring.

Taxodium/Nyssa swamp is representative of early stage upstream migrating shorezones as illustrated by its inner and middle positions Table 2-4. It did not occur in the outer estuary as its setting has succumbed to the effects of rising sea level, erosion and increased salinity. Mixed forest was representative of the flat wetland type (NCDENR 2003a), which occupied both outer estuary interstream divides and inner estuary paleo-braidplain settings. Therefore its presence reflects over-flat migration, as well as, upstream migration where shorezone is migrating upon paleo-braidplain setting.

Similarly, the percentage of woody vegetation within the shorezone was greater toward the inner estuary (Table 2-5). While *Morella* scrub swamp was clearly present in shorezones of the outer estuary, forests and other scrub-shrub cover types were restricted to the landward margin. For example, it was determined that *P. serotina* (transect O-3), mixed forest (transect O-1), and *Morella* scrub margin (transect O-2) communities were situated beyond the hydrologic influence of sea level, and thus are not considered shorezone.

Regional patterns in peat depth were subtle if they occurred at all (Table 2-6). The deepest profile, 430 cm, was observed in a submerged valley of Hancock Creek, a tributary to the middle estuary. Rather, peat depth appeared more related to geomorphic settings

Table 2-5. Percent woody vegetation of shorezone according to sampling area.

Inner		Middle		Outer	
I-1	84	M-1	0	O-1	25
I-2	63	M-2	57	O-2	0
I-3	24	M-3	84	O-3	0
I-4	100				
I-5	16				
I-6	26				
Mean	52		47		8
SD	35		43		15

Table 2-6. Greatest depths of peat in centimeters according to sampling area.

Inner		Middle		Outer	
I-1	265	M-1	30	O-1	160
I-2	285	M-2	430	O-2	200
I-3	180	M-3	200	O-3	170
I-4	385				
I-5	160				
I-6	85				
Mean	227		220		177
SD	106		201		21

Table 2-7. Greatest depths of peat in centimeters according to hydrogeomorphic wetland type (NCDENR 2003a). Transect M-1 is mapped as upland in the wetland map.

Riverine		Upland		Flats	
I-1	265	M-1	30	O-1	160
I-2	285			O-2	200
I-3	180			O-3	170
I-4	385			I-5	160
M-2	430			I-6	85
M-3	200				
Mean	291				155
SD	99				42

(Table 2-7). Though not statistically significant, riverine transects exhibited greater peat depth than those of flats. This pattern supports the space-for-time framework of Chapter 1 using peat depth as a proxy for exposure to sea level. Ages of basal peats >20 m deep extracted from drowned river valley settings of the A-P system have been estimated to have formed >10 kyr BP (Culver *et al.* 2008). Basal peat 0.8 m deep extracted from the submerged interstream divide flat at the outer estuary sampling area measured approximately 1.6 kyr BP (Young 1995).

Conclusion

This study developed a multi-level hierarchical classification that contributed a clearer understanding of patterns in irregularly flooded estuarine shorezones. The classification consists of 16 community types arranged into 6 cover types that are further arranged into 4 wetland types. Each level of the classification was intended to represent a particular ecological scale of analysis (*sensu* Urban *et al.* 1987). For example, the first order of classification, hydrogeomorphic setting, relates to Chapter 1 in which patterns in wetland type were used to illustrate the ecological effects of rising sea level at a landscape scale. Here in Chapter 2, analyses performed at a plant community scale revealed both local and regional patterns of zonation. In Chapter 3, the cover type level of classification was applied to map and quantify changes in vegetation at a shorezone scale that may be related to sea-level rise.

This study also revealed that *Persea* forest (Maritime Scrub Swamp; Schafale and Weakley 1990), previously known only to occur in interdune swales of back barrier islands of the Outer Banks, may have a considerably broader range. Further, the swamp and ghost forest subtypes of the *Morella* scrub community exhibited similar species composition to *Persea* forest suggesting that they may be an early precursor to the development of *Persea* forest. Should this be the case, it would extend the potential range of Maritime Scrub Swamp described by Schafale and Weakley (1990) to the inner most portions of the Neuse River estuary. How rising sea level will affect this seemingly rare ecological community, among others, requires further study.

Salinity and hydroperiod are ultimately responsible for the zonation of plant communities observed within shorezones wetlands of the Neuse River and western Pamlico

Sound estuary. The DCA ordination provided additional clarity in ordering cover types within the hierarchical classification relative to an apparent salinity gradient. These data also suggest that zonation was more apparent at the outer estuary than in the inner estuary. For example, transects at outer estuary sampling areas exhibited between 5 and 7 communities per transect where as transects at the inner estuary sampling area exhibited between 2 and 5 community types. While this study provides limited information about disturbance caused by wrack deposition, it has been found to affect shorezone community dynamics (Knowles 1989, Tolley and Christian 1999, Miller *et al.* 2001, Poulter 2005). The role of fire in influencing community composition was not clear. However, wrack deposition interrupts the pattern of zonation, thus producing the mosaic-like pattern described by earlier studies (Brown 1959, Burk 1962, Cooper and Waits 1973). Therefore, this study suggests that irregularly flooded shorezones, particularly marshes, simultaneously exhibit both zonal and mosaic patterns of vegetation. Furthermore, the lack of regular tidal inundation softens the zonation allowing the characteristic mosaic pattern to be more apparent than in tidal salt marshes.

Chapter 3

Vegetation change dynamics and transgression of an outer estuary shorezone:

a shorezone scale analysis

Introduction

Wind, astronomical tides, and storm surges cause fluctuations in estuarine water levels that prevent a geographically static separation between land and sea (Riggs and Ames 2003). Therefore where sea level and the terrestrial environment intersect, a continuum of vegetation types occur that can be arranged and classified as zones (Adams 1963, Bertness 1991, Pennings and Callaway 1992, Pennings *et al.* 2005). These zones are collectively referred to here as the shorezone. As sea level rises, the terrestrial environment is inevitably submerged as the landward margin of shorezone migrates up the terrestrial slope. Shorezones will increase, decrease, or maintain area as they transgress depending upon rates of shoreline erosion, rates of vertical accretion, and landward slope (Chapter 1)

As the shorezone transgresses over land, terrestrial plant communities are inevitably displaced by those better adapted to increased inundation and salinity. While this process is often perceived as a function of sea-level rise, changes in shorezone vegetation tend to be the result of other external abiotic factors including wrack deposition and blow downs caused by storms, tree mortality in response to drought or fire, or ditching and clear cutting of forests caused by humans (Ross *et al.* 1994, Michener *et al.* 1997). The disturbances they cause tend to be both spatially and temporally stochastic, thus triggering local to widespread environmental change (Clark 1986). Such disturbances effectively create conditions that facilitate the landward migration of shorezone plant communities. For example, hurricanes and nor'easters are capable of generating large surges that promote saltwater intrusion into previously freshwater systems, thus altering soil water chemistry and stressing vegetation (Chabreck and Palmisano 1973, Brinson *et al.* 1985). Storms can also exacerbate the effects of erosion at the shoreline and topple trees and shrubs creating gaps in the forest canopy

(Williams *et al.* 2003). Forest fires may kill trees reducing evapotranspiration, temporarily raising the surface ground water table. Fires may also burn the surface layers of organic soils lowering the soil surface elevation to or below the normal water table (Poulter 2005).

While disturbances play a critical role creating conditions that may be conducive to landward migration of vegetation, plants within the shorezone may also exhibit biotic mechanisms to resist environmental change (Brinson *et al.* 1995). Mature trees tend to be more resilient to salt stress caused by storm surge inundation than younger trees, tree seedlings, and herbaceous understory vegetation (Conner *et al.* 1994). Maintenance of the forest canopy inhibits invasion by shade-intolerant marsh plants that might otherwise out compete tree seedlings (Brinson *et al.* 1995). Additionally, forests exhibit a higher rate of evapotranspiration that may draw down the local water table to levels more conducive to forest species than to marsh species (Poulter 2005). Conversely, fire may also promote resiliency. More frequent but less severe fires may facilitate regeneration of shorezone forests by opening serotinous pine cones and dispersing seeds or by eliminating competing marsh vegetation (Poulter 2008c). Frequent fires may also reduce accumulations of fuel and are less likely to damage the forest canopy.

Anthropogenic disturbances may have significant effects on shorezone communities as well. Shirley and Battaglia (2006) found that urbanization and hydrologic modifications impeded landward migration of shorezone vegetation at various locations along the north coast of the Gulf of Mexico. Conversely, extensive ditching of freshwater shorezones of the Albemarle-Pamlico Peninsula in North Carolina has greatly increased the potential for landward expansion of brackish marshes (Pearsall and Poulter 2005).

Studies have implied that landward migration of vegetation is permanent (Williams 1999, Gaiser *et al.* 2002, Desantis *et al.* 2007). However, this assertion neglects ecosystem resilience that may restore previous conditions and thus plant communities. Therefore, while disturbances may initially alter environmental conditions and species composition, if conditions return to those prior to disturbance, the previous community may be restored through ecological succession (Clark 1969) rather than resulting in state change.

In this chapter, historical aerial photographs were used to map changes in vegetation and shoreline over a 40 year period. A DEM was also used to model displacement of the landward margin of shorezone as a factor of sea-level rise. A series of ranked cover types (Chapter 2) were used to represent a generic sequence of vegetative cover between the shoreline and landward margin. Throughout the chapter, the terms landward migration, seaward migration, and transgression are used to describe differing dynamic processes. Landward migration describes alterations in plant community composition to species better adapted to the influences of estuarine waters, presumably caused by various disturbances or salt stress. Seward migration is used to describe alterations in plant community composition to species better adapted to freshwater influences, presumably due to a lack of disturbance or salt stress. Transgression describes the landward movement of shorezone and its landward margin.

Methods

Outer estuary interstream divide unit S8 was selected for mapping. Only the area between the 1958 shoreline and the 1 m elevation contour (NAVD 88) were analyzed for change. This area is hereafter referred to as potential shorezone (PSZ). Areas above 1 m elevation, designated non-shorezone, and the Holocene barrier adjacent to Pamlico Sound (Figure 3-1) were excluded from analysis. Areas above 1 m elevation were not mapped for change with the exception of those areas replaced by estuarine water, presumably through shoreline erosion.

Aerial photographs and GIS

Aerial photography from 1958 and 1998 was used in this analysis. The 1958 aerial photography was flown by the US Department of Agriculture, Commodity Stabilization Service between fall 1958 and winter 1959. It was digitized from 9 x 9 inch (1:20,000 scale) panchromatic analog prints acquired from the North Carolina Geologic Survey archives. Digitization was performed using a Microtek ScanMaker 9800XL® high resolution large format flatbed scanner equipped with a linear array charged coupled device digitizer. Prints were scanned at a resolution of 600 pixels per inch (42.34 μm) as this appeared to be the maximum resolution of the prints themselves. The corresponding ground resolution of these images, once georeferenced, was approximately 0.64 m^2 per pixel.

The 1998 aerial photographic dataset consisted of color infrared Digital Orthophoto Quarter Quadrangles (DOQQs) recorded during leaf-off in 1998 and 1999. The DOQQs are part of a national data set of color infrared aerial photography that exhibits a ground resolution of 1.0 m^2 per pixel. They were employed as the base map upon which the 1958 aerial photographs were georeferenced. Comparable applications of this method are

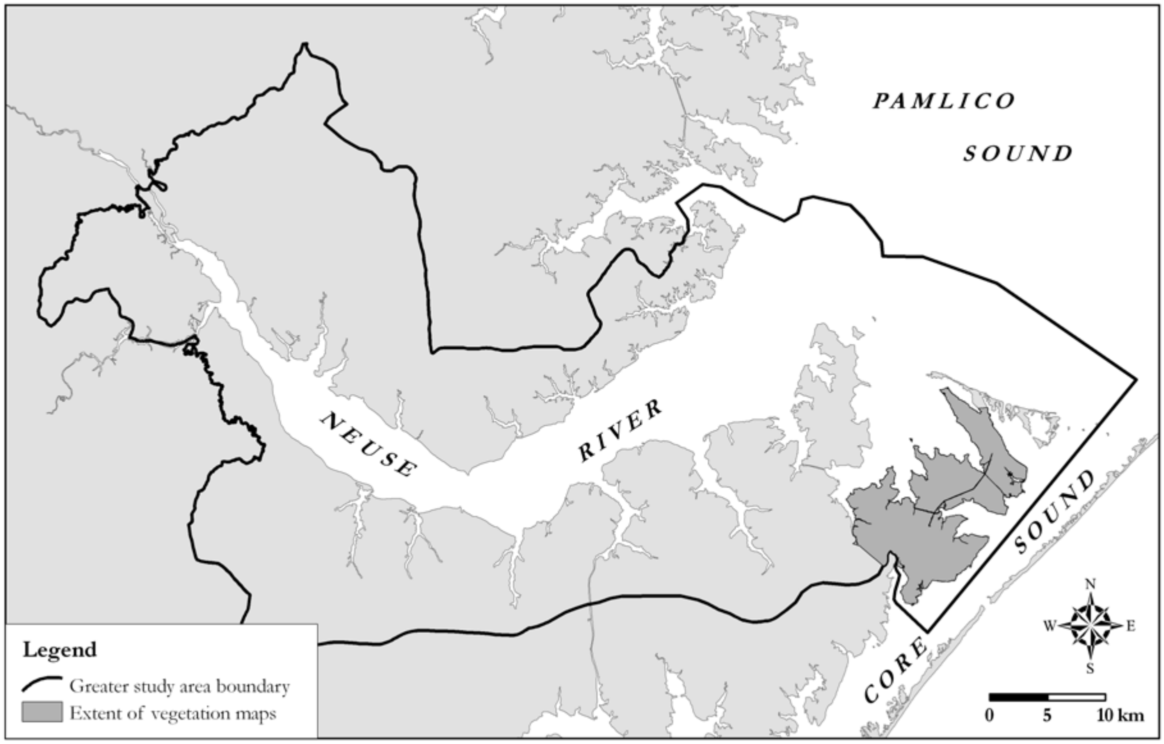


Figure 3-1. Location of shorezone vegetation maps within the context of the greater study area.

provided by Kastler and Wiberg (1996), Erwin *et al.* (2004), Higinbotham *et al.* (2004), and Poulter (2005).

True-color DOQQs recorded leaf-on in 2006 were used to help verify interpretations. They were acquired from the US Department of Agriculture, National Agriculture Imagery Program. These images were not employed for mapping as they were not acquired until late 2007 and failed to co-register precisely to the 1998 DOQQs.

Georeferencing, mapping and spatial analyses were performed using Environmental Systems Research Institute ArcGIS® 9.1/9.2 software. All data were projected to the North Carolina State Plane coordinate system (units in meters) cast to North American Datum 1988. The georeferencing tool was used to co-register the 1958 aerial photographs to the 1998 DOQQs using a second-order polynomial transformation. Between 6 to 12 ground control points were attempted per photograph.

Because the study area covered relatively unpopulated areas of marsh, forest, and open water, there were few fixed objects such as roadway intersections or other human structures for use as ground control. Alternatively, ditch intersections, marsh potholes, narrow creek confluences, and narrow creek meanders, which appeared relatively stable between time steps, were used for ground control. Similar methods have been employed by Erwin *et al.* (2004), Kastler and Wiberg (1996), and Poulter (2005). These natural ground control points were actually preferred by the author as they exhibited greater consistency over time than did roadway intersections, which are prone to realignment. Upon completion of georeferencing, each individual photograph was visually inspected for accurate co-registration with the respective DOQQs regardless of the respective root mean squared error (RMSE) value derived from the polynomial transformation.

Cover types, rank, and interpretation

A series of six vegetated cover types were established in Chapter 2. Those classes were combined with three unvegetated classes and ranked 1 through 9. Ranking was performed to reveal information as to the direction (landward vs. seaward) and magnitude (score) of changes. Ranks were assigned as a model of each class's position relative to the shoreline and the landward margin of shorezone (*i.e.*, low ranks are closer to the shoreline while higher ranks are closer to the landward margin). Cover types and their respective ranks are as follows: estuarine water (1), ponded water (2), non-vegetated surface (3), low brackish marsh (4), high brackish marsh (5), oligohaline marsh (6), oligohaline marsh/scrub-shrub (7), scrub-shrub (8), forest (9). Two additional cover types, ditched brackish marsh and altered land, were not assigned ranks because they were related to anthropogenic disturbances.

Transect locations recorded with a GPS in the field were uploaded to the GIS and used as training sites to verify interpretations of aerial photographs. Community types were labeled according to their respective cover types and their boundaries were superimposed onto aerial photographs as they occurred along transects (Figures 3-2, 3-3, and 3-4). Because the 1998 DOQQs were nearly a decade old at the time this study began, the 2006 DOQQs were implemented as a more current reference to aid with verifying interpretations. Transect locations are reported in Table 2-1 and depicted in Figure 2-1 of Chapter 2. Descriptions of cover types and how they were interpreted from the 1998 DOQQs (recorded in the color infrared spectrum) are described below.

All area seaward of the shoreline was regarded as estuarine water and assigned the lowest rank (1). Ponded water consisted of areas inundated by water but lacked significant vegetative cover. Ponded water was typically surrounded by low brackish marsh and was distinguishable from estuarine water by its interior position. It was assigned the next rank (2) with the assumption that, if an area is unvegetated and inundated in a high salinity environment, it is unlikely to revegetate. Unvegetated storm levees, mudflats, strand plains, and salt pannes were classified as non-vegetated. These areas generally exhibited high reflectance and were relatively homogeneous. They received a rank of 3 under the assumption that they were more suitable to support vegetation than areas classified as ponded water.

Low brackish marsh (4) was identified by its heterogeneous mosaic of dark maroon and light blue patches (Figures 3-2, 3-3, and 3-4, 1998 DOQQs). *Juncus* marsh is the major constituent of this cover type while *S. alterniflora/Juncus* marsh, *S. alterniflora* fringe, and mixed marsh levee were typically less prevalent along shorelines (see Chapter 2). The darker hues of low brackish marsh may be attributed to inundation. High brackish marsh (5) exhibits comparable colors and patterns to low brackish marsh; however, it was generally lighter in color (Figure 3-4, 1998 DOQQ). Field observations suggest that these areas exhibit the mixed marsh interior community type. High brackish marsh tends to occur landward of low brackish marsh. Oligohaline marsh (6) was identified by a relatively consistent fine texture pattern of light pink to beige hues (Figure 3-2, 1998 DOQQ). The *Cladium* marsh community type is the primary constituent of oligohaline marsh in the outer estuary. Oligohaline marsh/scrub-shrub (7) exhibited a matrix similar to Oligohaline marsh although it was mottled with patches of red, indicative of evergreen shrubs and/or trees (Figure 3-2, 1998 DOQQ). While the *Cladium* scrub community type was not observed in the outer estuary during sampling, it is believed representative of the Oligohaline marsh/scrub-shrub cover type. Scrub-shrub (8) was identifiable by a fine textured red pattern mottled by

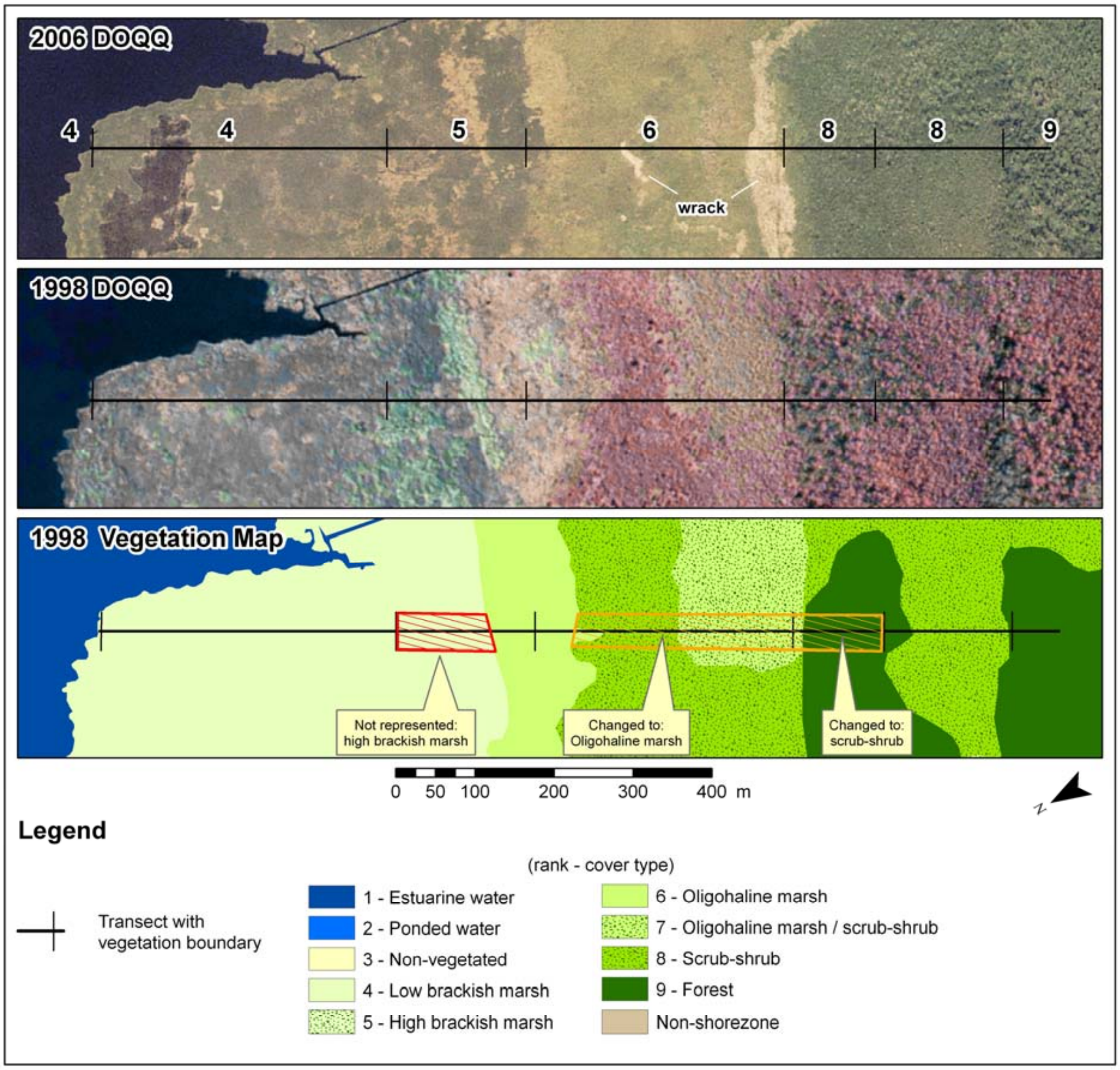


Figure 3-2. Transect O-1 training site. Community types observed along the transect are labeled according to their respective cover type rank (see legend) superimposed above the 2006 DOQQ. 1998 DOQQ base map from which the 1998 vegetation map was derived is provided for reference. Disagreements between field observations and the map designation are identified on the 1998 vegetation map. Those highlighted in red are attributed to error; those highlighted in orange are attributed to change.

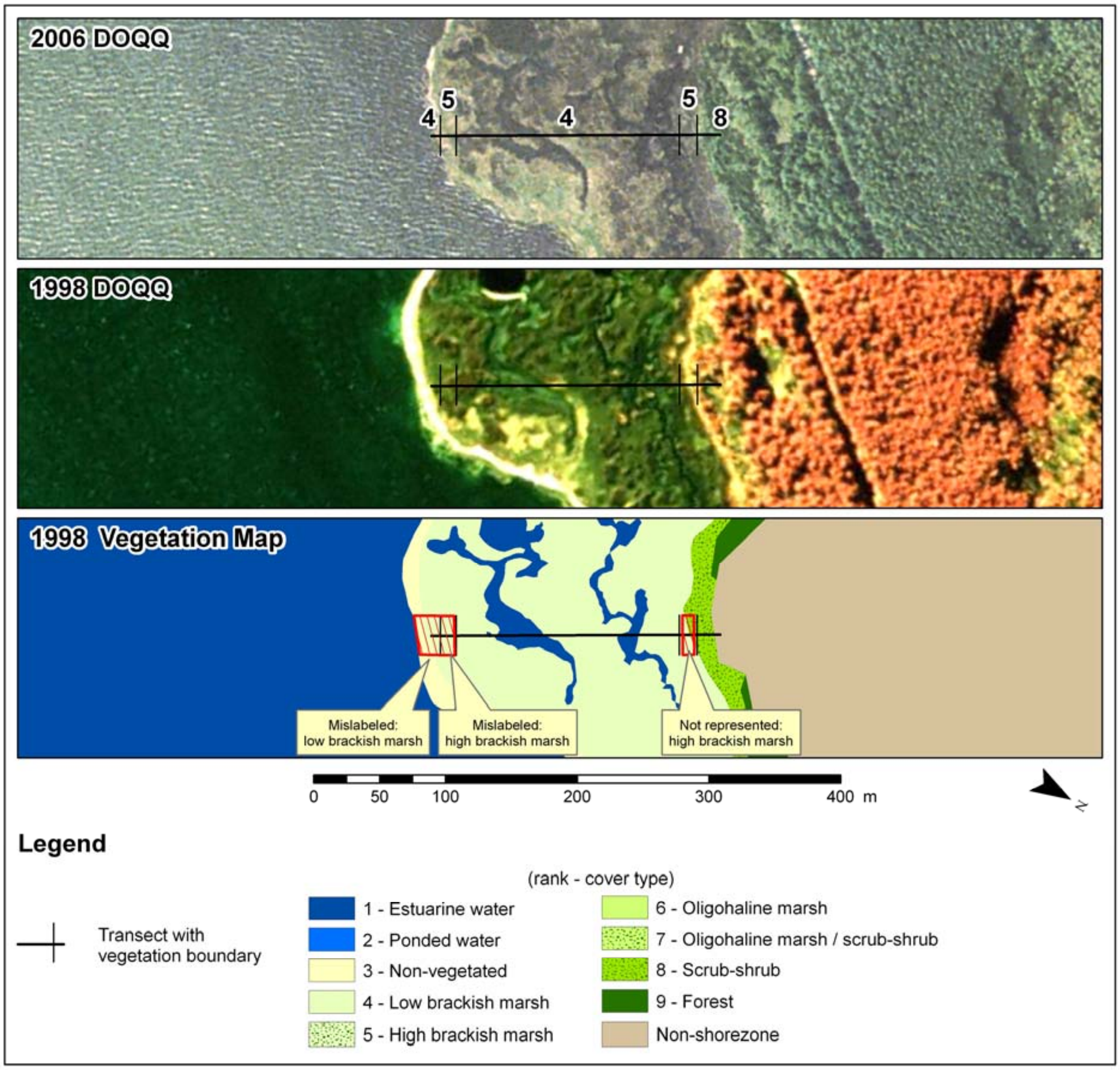


Figure 3-3. Transect O-2 training site. Community types observed along the transect are labeled according to their respective cover type rank (see legend) superimposed above the 2006 DOQQ. 1998 DOQQ base map from which the 1998 vegetation map was derived is provided for reference. Disagreements between field observations and the map designation are identified on the 1998 vegetation map. Those highlighted in red are attributed to error; those highlighted in orange are attributed to change. Note that the shoreline and adjacent communities have migrated landward since 1998.

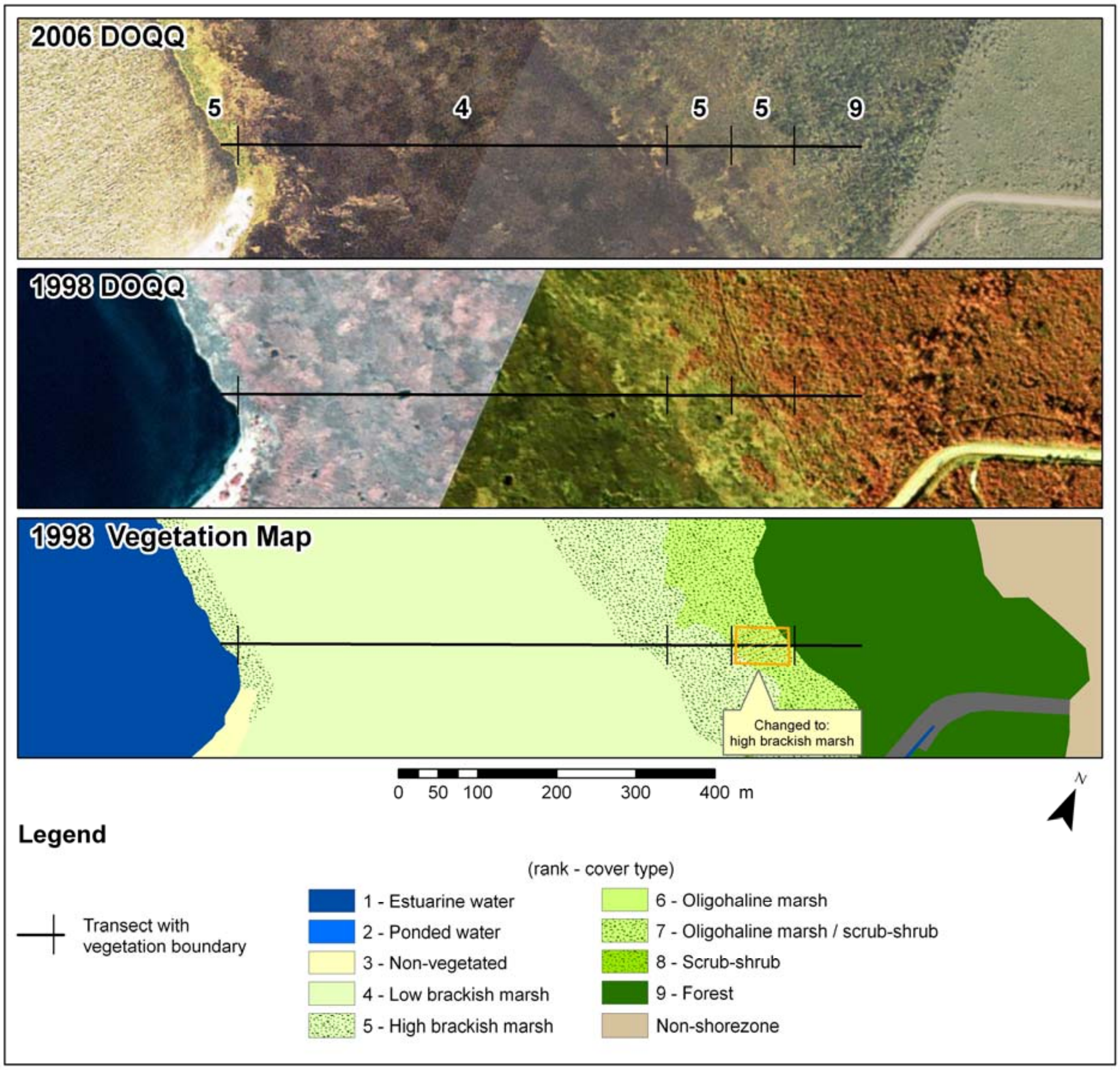


Figure 3-4. Transect O-3 training site. Community types observed along the transect are labeled according to their respective cover type rank (see legend) superimposed above the 2006 DOQQ. 1998 DOQQ base map from which the 1998 vegetation map was derived is provided for reference. Disagreements between field observations and the map designation are identified on the 1998 vegetation map. Those highlighted in red are attributed to error; those highlighted in orange are attributed to change.

shadows of shrubs. *Morella* scrub margin and *Morella* scrub swamp are the two community types associated with the scrub-shrub cover type (Figures 3-2 and 3-3, 1998 DOQQs). Forest cover (9) was distinguishable from scrub-shrub by a coarser textured pattern (red if evergreen, brown to blue-gray if deciduous) in addition to the longer shadows of tree trunks and canopy (Figures 3-2 and 3-4). Mixed forest and *P. serotina* scrub are two community types observed in the field. Forest cover received the highest rank (9) as it represents the terrestrial end member of the vegetation continuum across the shorezone (*i.e.*, forest exhibit limited if any halophytic vegetation). Altered land primarily reflects areas that had been cleared for agricultural, residential, or commercial purposes. Ditching of low brackish marshes occurred sometime after 1958, purportedly for mosquito control.

Cover types were delineated as vector-based polygon maps over the digital aerial photographs. Delineation was performed heads-up (*i.e.*, on screen) between 1:500 to 1:3000 scales. A minimum mapping unit of approximately 100 m^2 was specified. Interpretation of cover types from aerial photographs was performed manually. Automated image classification methods were not possible because the two datasets were recorded using different spectra and exhibited markedly different reflectance among individual photographs (Jensen 2005).

The DEM was used to estimate change in the position of the landward margin (i.e. the extent of sea level's hydrologic influence) because it is not possible to detect this change through the interpretation of aerial photographs. To accomplish this, the estimated rate of sea-level rise (3.8 ±0.6 mm/yr; Chapter 1) was multiplied by 40 years. The result was an estimated rise of approximately 0.15 m between 1958 and 1998. Using the DEM, the area of land situated between the 1 m contour and the 0.85 m contour was mapped and excluded from the 1958 PSZ map. This area was thereafter treated as the increase in PSZ as a result of sea-level rise.

Accounting for and reducing error

A variety of sources of error arise from using aerial photographs to map vegetation. These complications stem from georeferencing aerial photographs, delineating boundaries between communities, subjectivity of interpretation, erroneously labeled polygons, and overlapping polygons and gaps (Green and Hartley 2000). In this study, multiple strategies were employed to minimize mapping error. The first involved employing a retrospective approach in which present conditions are related to the past (Kaykho and Skanes 2006). This was accomplished by duplicating the 1998 vegetation map, overlying it on the 1958 aerial photographs, and editing only areas that appeared to have changed. Most importantly, this procedure minimized false changes related to the subjectivity of interpretation. Secondly, it helped to minimized erroneous sliver polygons that result from digitizing identical vegetation boundaries (*i.e.*, they have not changed) independently in both maps. Sliver polygons ultimately reflect false change and can amount to significant error over large study areas such as here (Green and Hartley 2000).

Error originating from multi-interpreter subjectivity was eliminated by using a single interpreter. Day to day subjectivity was minimized through an iterative process of reviewing interpretations for consistency across the entire map at least three times. Labeling errors were minimized by designing a map legend consisting of colors and patterns and visually inspecting each map for conflicts. These inspections were performed heads-up between the same scales specified for digitization. Following inspections, topologies were built to remove gaps and correct overlapping polygons.

Upon completion, the two maps were joined into a single file with the union geoprocessing tool. This process combined cover type and rank from both dates into a single geodatabase feature class, and thus attribute table. Attribute values from the 1958 rank column were then subtracted from 1998 rank column using the field calculator. Outcomes produced both positive and negative scores that were used to identify both the direction and magnitude of any changes that had occurred. Areas that did not change class received a score of zero. Negative values reflected changes in a landward direction whereas positive values reflected change in a seaward direction. For example, if an area was low brackish marsh (rank = 4) in 1958 and was replaced by estuarine water (rank = 1) in 1998, that polygon received a score of -3 (*i.e.,* the area shifted three classes in a landward direction and is now inundated by estuarine water). Conversely, if an area was scrub/shrub (rank = 8) in 1958 and replaced by forest (rank = 9) in 1998, the polygon received a score of +1 (*i.e.,* such an area may have suffered a disturbance prior to 1958 but has since regenerated, shifting only one class in a seaward direction).

A standardized accuracy assessment to determine ground truth was not feasible as the 1998 DOQQ's were nearly 8 years old at the time mapping began. Therefore, disagreements between map data and ground truthed field data were likely to reflect vegetation change, rather than error. Nonetheless, once mapping was complete, the 1998 vegetation map was compared with the training sites. Aerial photographs from 2006 helped to recognize whether disagreements were the result of error or vegetation change. Cover type rank was also compared with the results of the DCA vegetation ordination of Chapter 2.

Results and Discussion

Accuracy assessment

Co-registration of 1958 aerial photographs to the 1998 DOQQs was highly accurate. Mean root mean square error (RMSE) of 26 georeferenced aerial photographs amounted to 1.68 m; therefore, any particular point on a 1958 photograph can be expected to fall within 1.68 ± 0.31 m of its respective position on the 1998 DOQQ base map (Table 3-1).

Ground truth for the 1998 map is estimated at 92 % accuracy (Table 3-2). The majority of disagreement in classification was associated with high brackish marsh (rank = 5). This was to be expected as distinct boundaries between high brackish marsh and low brackish marsh were sometimes difficult to distinguish, particularly in the vicinity of transect O-1. When in doubt, low brackish marsh was generally designated in lieu of high brackish marsh (Figure 3-2). Other disagreements associated with high brackish marsh can be attributed to its occasionally narrow areal extent, particularly adjacent to shorelines atop storm levees (Figure 3-3). Recent disturbances by fire and confusion between high brackish marsh (field) and oligohaline marsh/scrub-shrub (map) along transect O-3 (Figure 3-4) suggests change as opposed to misrepresentation. Likewise, scrub-shrub and forest cover types toward the landward margin of transect O-1 have clearly diminished since 1998.

Cover type rank exhibited a strong correlation with axis 1 of the detrended correspondence analysis performed in Chapter 2 (tau = 0.799), thus validating the use of rank as measure of a cover types adaptation to the influence of sea level (Figure 3-5). Kendall's Tau, a non-parametric correlation coefficient, is employed because rank not a continuous variable.

Table 3-1. List of georeferenced aerial photograph used to create 1958 vegetation map, the associated route mean square error (RMSE) and number of ground control points (GCPs) located for each photograph. A statistical summary is located below.

Frame	RMSE	GCPs
bus_1w_15	0.59	12
bus_1w_16	3.00	14
bus_1w_17	1.99	15
bus_1w_29	2.42	20
bus_1w_30	2.74	13
bus_1w_31	1.96	13
bus_1w_32	2.85	16
bus_1w_33	2.24	16
bus_1w_35	0.60	9
bus_1w_4	0.51	9
bus_1w_41	1.02	9
bus_1w_41	1.02	9
bus_1w_42	2.79	13
bus_1w_43	1.77	13
bus_1w_44	1.93	13
bus_1w_46	0.92	12
bus_1w_47	2.02	13
bus_1w_48	1.20	8
bus_1w_5	0.47	10
bus_1w_50	1.56	12
bus_2w_10	1.96	12
bus_2w_14	1.78	10
bus_2w_15	1.83	12
bus_2w_7	0.64	11
bus_2w_8	1.99	10
bus_2w_9	1.85	14
Summary statistics (*n* = 26 aerial photographs)		
Minimum	0.47	8
Mean	1.68	12
Maximum	3.00	20
Standard deveation	0.77	3
Standard error	0.31	

Table 3-2. Estimated accuracy of 1998 vegetation map. Key to cover type rank as follows: 4 – low brackish marsh, 5 – high brackish marsh, 6 – oligohaline marsh, 7 – oligohaline marsh/scrub-shrub, 8 – scrub-shrub, 9 – forest. Disagreements between field data and the map may be errors or the result of vegetation change that has occurred since 1998. “Not represented” identifies disagreements where a particular cover type was not represented because of the inherent difficulty of disinviting a boundary between it and other cover types. “Mislabeled” identifies areas that were labeled incorrectly on the map.

Cover type rank		Disagreement	Percent of transect	
field	map		accurate	error
Transect: O-1				
4	4		0	
4	4		29	
5	4	not represented		15
6	8	change	25	
8	9	change	9	
8	8		14	
9	9		8	
		Sub-total	85	15
Transect: O-2				
4	3	mislabeled		1
5	3	mislabeled		2
4	4		87	
5	4	not represented		6
8	8		4	
		Sub-total	91	9
Transect: O-3				
5	5		5	
4	4		72	
5	5		11	
5	7	change	9	
9	9		4	
		Sub-total	100	0
		Mean	92	8

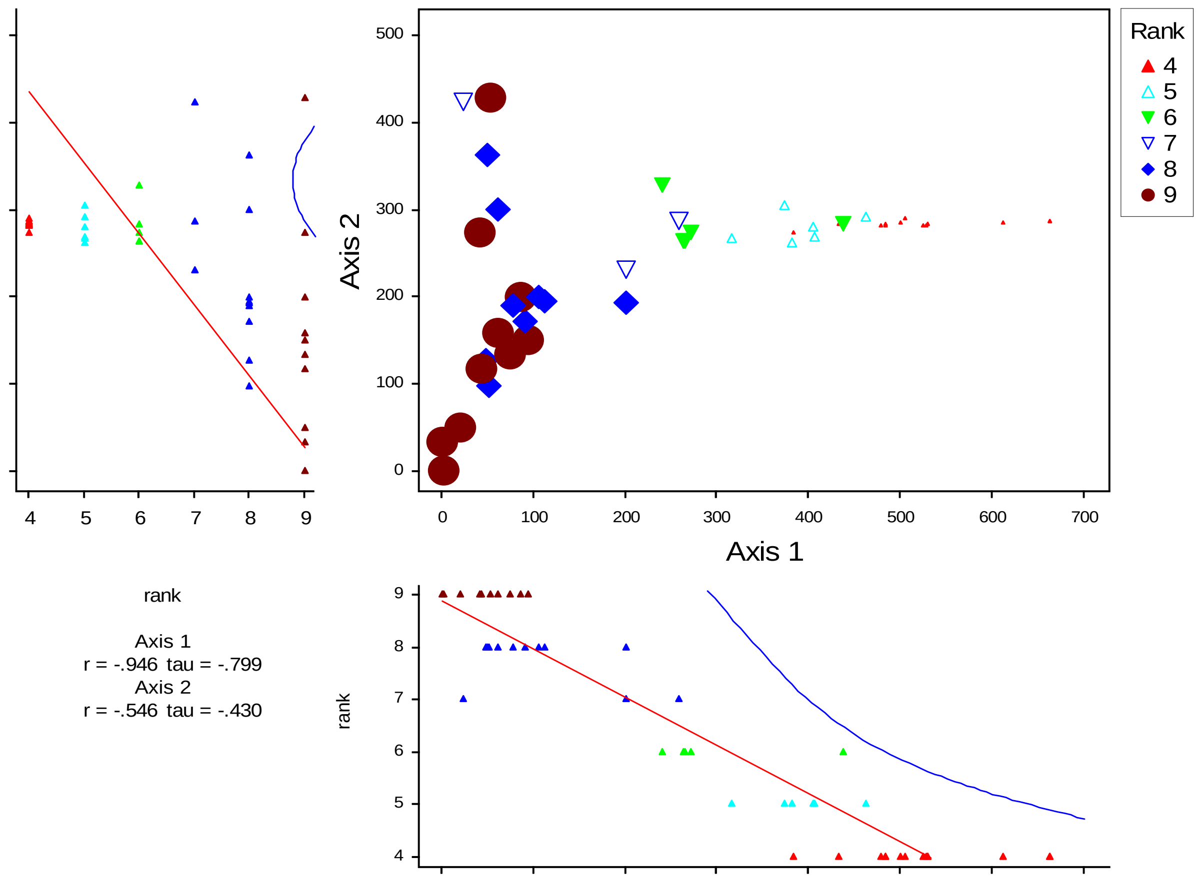


Figure 3-5. Correlation between cover type rank and axis scores of the detrended correspondence analysis performed in Chapter 2. The strong correlation between rank and axis 1 (tau = -0.799) validates the assumed sequence of cover type positions relative to the shoreline and the landward margin of shorezone (plotted below ordination diagram). In Chapter 2, axis 1 was determined to represent a salinity gradient between the shoreline to the landward margin of shorezone. Correlation between axis 2 and rank is insignificant (plotted to the left of the ordination diagram). Key to cover type rank is as follows: 4 – low brackish marsh, 5 – high brackish marsh, 6 – oligohaline marsh, 7 – oligohaline marsh/scrub-shrub, 8 – scrub-shrub, 9 – forest.

Composition of potential shorezone

Cover types were delineated over 7,422 ha of PSZ that existed between both 1958 and 1998. The remaining area, non-shorezone, amounted to 3,942 ha of land situated above 1 m elevation and was excluded from analysis with the exception of those areas replaced by estuarine water. Low brackish marsh dominated PSZ in both years accounting for 69.0 % (4,986.5 ha) of its area on average, followed by forest at 12.7 % (919.1 ha), scrub-shrub at 4.5% (325.5 ha), and altered land at 4.4 % (320.3 ha) (Tables 3-3a and 3-3b). Vegetation maps of 1958 and 1998 are presented in Figure 3-6. Differences in vegetation maps are subtle at this scale. Therefore, Figure 3-7 was developed to illustrate where changes have occurred as well as the landward/seaward direction and magnitude of those changes. Lastly, Figure 3-8 depicts changes at the shoreline (*e.g.*, PSZ lost to estuarine water due to shoreline erosion) and the landward margin of PSZ (*e.g.*, estimated increase in PSZ area due to sea level rise). The cumulative loss of PSZ at the shoreline and gain at the landward margin translates to the net transgression of PSZ as a whole.

Change in potential shorezone

In total, 80.3% (5,734.8 ha) of 1958 PSZ remained stable while 19.7% (1,410.9 ha) appeared to exhibit some form of change (Table 3-4). Low brackish marsh appears to have been most stable over the study period losing only 0.2% (11.4 ha) of its area (Tables 3-3a and 3-3b). High brackish marsh, oligohaline marsh, and oligohaline marsh/scrub-shrub appear to have suffered the greatest losses, -17.1% (-51.1 ha), -67.7% (-260.1 ha), and -70.6% (-107.0 ha) of their 1958 area, respectively. Non-vegetated areas decreased by -49.3% (-23.5 ha); however, confusion of this cover type with high marsh in 1958 may be responsible for its large decrease (see Table 3-2). Scrub-shrub and forest cover types appear to have expanded

Table 3-3a. Percent of area, percent differences, and average percent of area of potential shorezone (PSZ).

Cover type	Percent of PSZ		Gross increase/decrease		Average
	1958	1998	percent of cover type	percent of 1958 PSZ	percent of PSZ
Ponded water	0.2	0.2	17.2	0.0	0.2
Non-vegetated	0.7	0.3	-49.3	-0.3	0.5
Low brackish marsh*	69.8	68.2	-0.2	-0.1	69.0
High brackish marsh	4.2	3.4	-17.1	-0.7	3.8
Oligohaline marsh	5.4	1.7	-67.7	-3.6	3.5
Oligohaline marsh/scrub-shrub	2.1	0.6	-70.6	-1.5	1.4
Scrub/shrub	3.4	5.6	71.3	2.4	4.5
Forest	10.4	15.0	48.4	5.0	12.7
Altered Land	3.9	4.9	27.8	1.1	4.4

* Includes ditched low brackish marsh cover type

Table 3-3b. Area, difference, and average area of cover types of potential shorezone. Units in hectares.

Cover type	Total cover 1958	Total cover 1998	Gross increase/ decrease	Avg. area
Ponded water	11.4	13.3	2.0	12.4
Non-vegetated	47.6	24.1	-23.5	35.8
Low brackish marsh*	4,991.0	4,982.0	-8.9	4,986.5
High brackish marsh	298.4	247.3	-51.1	272.8
Oligohaline marsh	384.5	124.3	-260.1	254.4
Oligohaline marsh/scrub-shrub	151.7	44.7	-107.0	98.2
Scrub/shrub	240.0	411.1	171.1	325.5
Forest	740.1	1,098.0	358.0	919.1
Altered Land	281.2	359.4	78.2	320.3
Total potential shorezone	7,145.7	7,304.3	158.6	7,225.0
Estuarine water	17.4	118.2	100.8	N/A
Non-shorezone	4,201.5	3,942.2	-259.4	N/A
Total area of study	11,364.6	11,364.6	0.0	11,364.6

* Includes ditched low brackish marsh cover type

Figure 3-6. Side-by-side comparison of 1958 and 1998 vegetation maps. Figure is on following page.

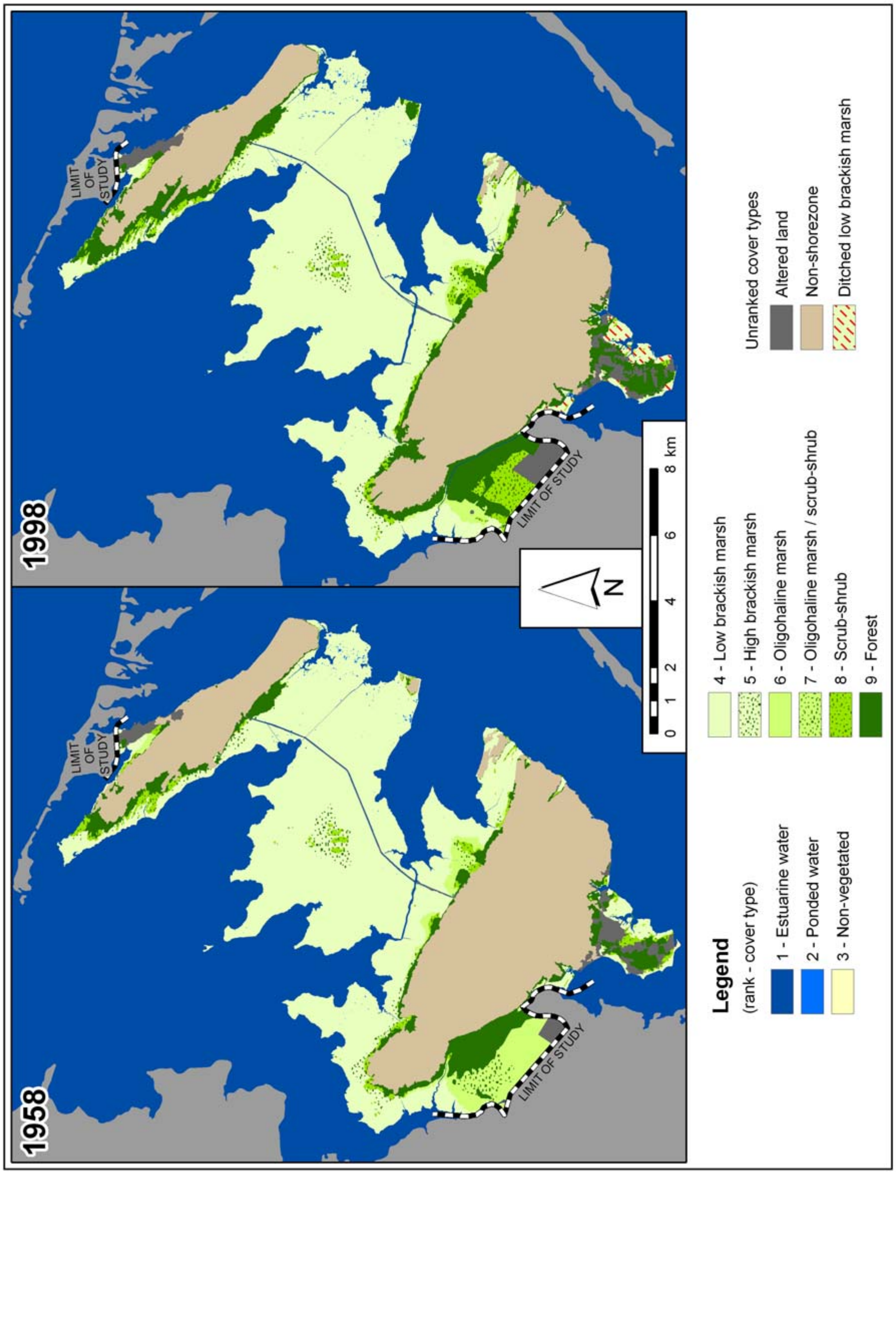

1958
1998
LIMIT OF STUDY
LIMIT OF STUDY
0 1 2 4 6 8 km
N
Legend
(rank - cover type)
1 - Estuarine water
2 - Ponded water
3 - Non-vegetated
4 - Low brackish marsh
5 - High brackish marsh
6 - Oligohaline marsh
7 - Oligohaline marsh / scrub-shrub
8 - Scrub-shrub
9 - Forest
Unranked cover types
Altered land
Non-shorezone
Ditched low brackish marsh

Figure 3-7. Direction and magnitude of vegetation changes. Direction is determined by score (*i.e.*, the sign (±) of the difference between 1958 and 1998 cover type ranks). Negative values reflect landward vegetation changes, positive values reflect seaward vegetation changes and 0 differences equate to no change. The bar chart located in the lower left corner illustrates the distribution of scores (quantities in hectares). The map inset includes the location where ponded water increased by 2.3 ha between 1958 and 1998. Figure is on following page.

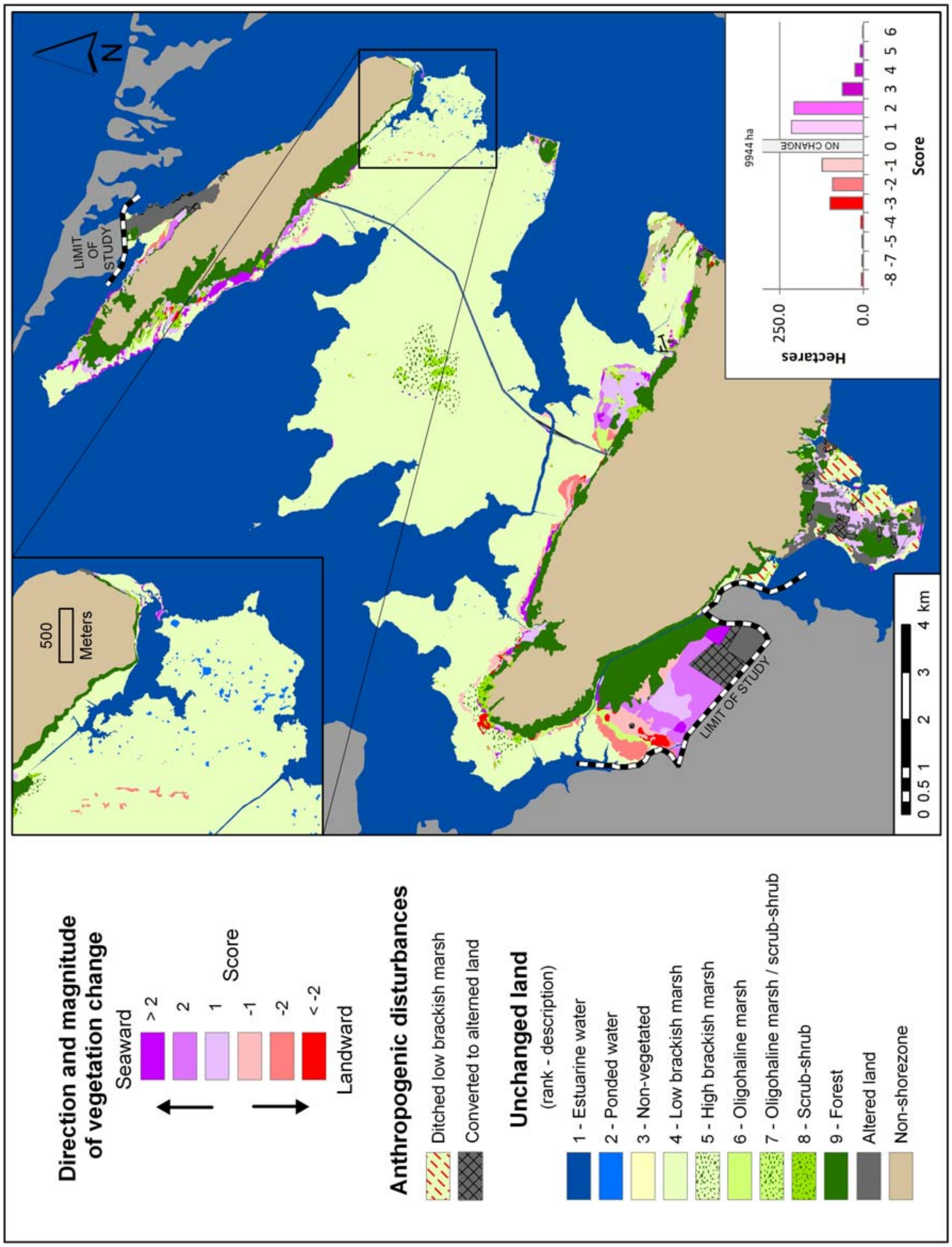

Direction and magnitude of vegetation change
Seaward
Landward
Score
> 2
2
1
-1
-2
< -2
Anthropogenic disturbances
Ditched low brackish marsh
Converted to altered land
Unchanged land
(rank - description)
1 - Estuarine water
2 - Ponded water
3 - Non-vegetated
4 - Low brackish marsh
5 - High brackish marsh
6 - Oligohaline marsh
7 - Oligohaline marsh / scrub-shrub
8 - Scrub-shrub
9 - Forest
Altered land
Non-shorezone
N
LIMIT OF STUDY
LIMIT OF STUDY
500
Meters
0 0.5 1 2 3 4 km
Hectares
250.0
0.0
9944 ha
NO CHANGE
-8 -7 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
Score

Figure 3-8. Potential shorezone (PSZ) transgression. Loss of PSZ to estuarine water was quantified as part of the overall vegetation mapping effort. PSZ gain was estimated using the DEM as opposed to delineating it from the aerial photography. Figure is on following page.

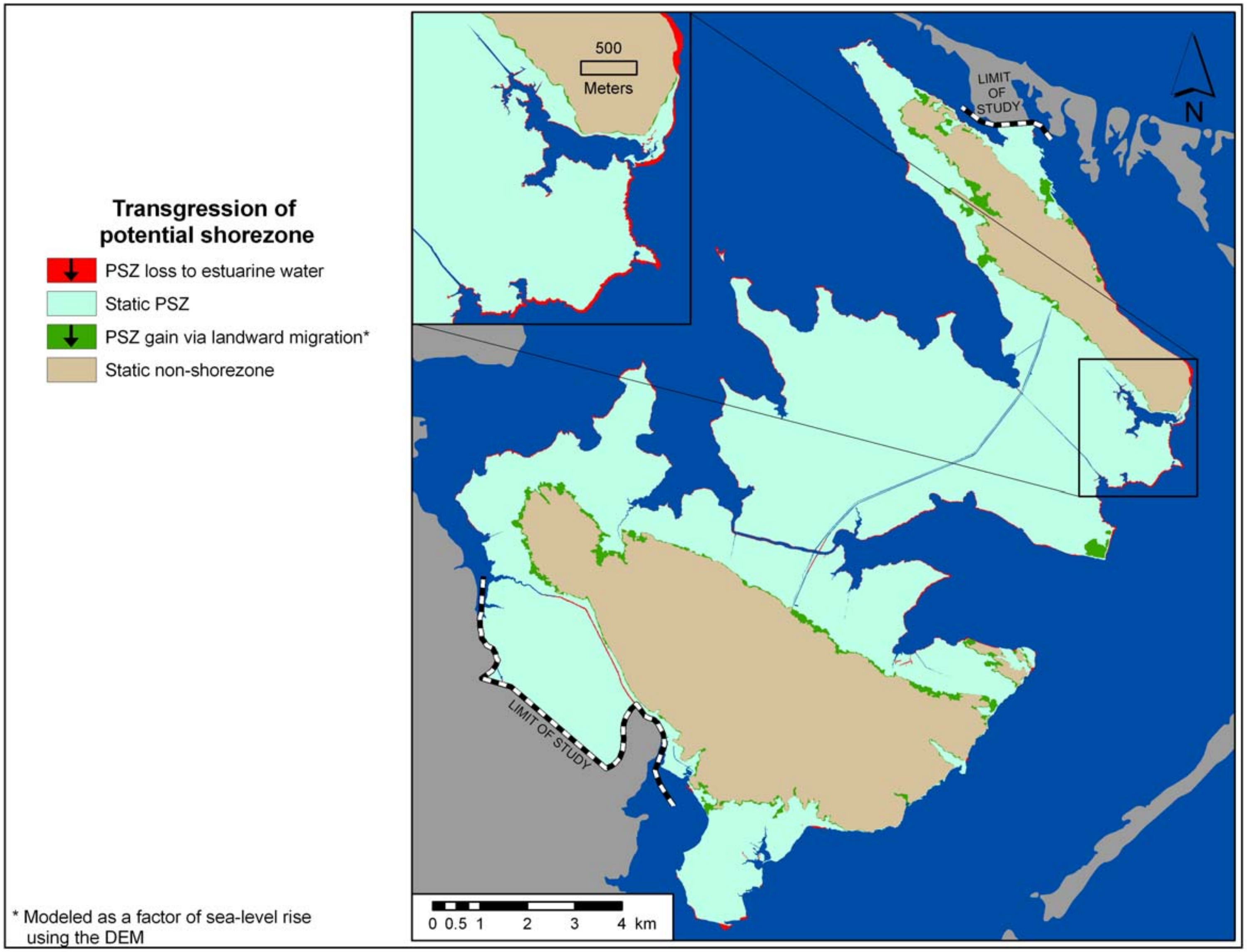

Transgression of
potential shorezone
PSZ loss to estuarine water
Static PSZ
PSZ gain via landward migration*
Static non-shorezone
* Modeled as a factor of sea-level rise
using the DEM
500
Meters
LIMIT
OF
STUDY
LIMIT OF STUDY
N
0 0.5 1 2 3 4 km

Table 3-4. Summary of potential shorezone (PSZ) change. Percents based on area of 1958 PSZ.

Nature of change	Area of change	
	(ha)	(%)
Seaward vegetation change	517.9	7.2
Landward vegetation change	234.8	3.3
PSZ loss to estuarine water	102.1	1.4
PSZ gain via overland migration*	249.7	3.5
Ditched low brackish marsh	123.7	1.7
Converted to altered land	119.0	1.7
Reverted to natural cover	63.6	0.9
Total area of change	1,410.9	19.7
No change	5,734.8	80.3
Non-shorezone to estuarine water	9.7	--

* Modeled as a factor of sea-level rise using the DEM.

the greatest with 71.3% (171.7 ha) and 48.4% (358.0 ha) increases to their original extents, respectively (Tables 3-3a and 3-3b). While ponded water occupied less than half of a percent of PSZ, its increase of 17.2% (2.0 ha) may be an important finding. Altered land increased by 27.8% (78.2 ha) of its original area.

Ninety three percent of all changes were replaced by cover types within 3 ranks of the original cover type (*e.g.*, scores >-3 to <3), 75% within 2 ranks and 39% within 1 rank (Figure 3-7, lower right inset). Landward changes appear near evenly distributed across scores -1 through -3. Seaward changes appear concentrated between scores of +1 and +2 and gradually taper off toward higher scores.

PSZ appears to have transgressed over the study period by losing 1.4% (102.1 ha) at the shoreline and gaining an estimated 3.5% (249.7 ha) at the landward margin (Table 3-4). Figure 3-8 illustrates these changes. However, despite transgression of PSZ itself, seaward migration of plant communities (7.2%, 517.9 ha) was twice that attributed to landward migration (3.3%, 234.8 ha) (Table 3-4). From these data, it does not appear that PSZ vegetation change is aligned with relative sea-level rise, at least not at the short temporal scale of this study. These data also suggest that scrub-shrub and forest in particular may be resisting environmental change through their resiliency to disturbances (*sensu* Brinson *et al.* 1995).

Table 3-5 is a change matrix that illustrates how much of each cover type changed to any other particular cover type. Nearly half of all changes attributed to landward migration (116.9 ha) are associated with changes to and from low brackish marsh (Table 3-6), which is not surprising given its dominance of PSZ. Additionally, 75.5 ha of low brackish marsh were replaced by estuarine water, while 63.5 ha of oligohaline marsh and 31.9 ha of high brackish

Table 3-5. Gross changes in potential shorezone vegetation. Units in hectares. Note: values are not reduced by changes in opposite direction.

From 1958: / To 1998:	Estuarine water	Ponded water	Non-vegetated	Low brackish marsh	High brackish marsh	Oligohaline marsh	Oligohaline marsh/scrub-shrub	Scrub/shrub	Forest	Ditched low brackish marsh	Altered land	Non-shorezone	Total cover 1958
Estuarine water	6.4	0.0	2.6	3.3	0.0					0.5	4.6		17.4
Ponded water	0.3	10.7	0.2	0.1		0.0							11.4
Non-vegetated	16.0		14.9	2.1	4.7	0.2		7.0	2.2	0.3	0.4		47.6
Low brackish marsh	75.5	2.3	5.1	4741.6	11.2	17.0	1.1	13.8	2.3	114.2	6.7		4991.0
High brackish marsh	0.0		0.3	31.9	207.3	0.3	10.9	34.7	12.2		0.7		298.4
Oligohaline marsh	0.7			63.5	8.8	56.1	26.6	131.9	22.9		73.9		384.5
Oligohaline marsh/scrub-shrub				6.5		32.9	4.3	67.5	39.4		1.2		151.7
Scrub/shrub	2.9		0.6	5.9	10.7	10.4		91.5	103.8	7.9	6.3		240.0
Forest	5.4			1.7	1.2	6.6	1.8	44.7	653.4	0.0	25.2		740.1
Ditched low brackish marsh													
Altered land	1.0			1.2				1.2	61.2	0.8	215.7		281.2
Non-shorezone	9.7	0.3	0.5	0.5	3.4	0.8		18.8	200.6	0.1	24.7	3942.2	4201.5
Total cover 1998	118.2	13.3	24.1	4858.3	247.3	124.3	44.7	411.1	1098.0	123.8	359.4	3942.2	11364.6

Legend

- Converted estuarine water (erosion)
- Landward vegetation change
- No change
- Seaward vegetation change
- Converted to potential shorezone (migration)
- Anthropogenic changes

Table 3-6. Summary of landward changes associated with low brackish marsh.

Score	Cover type	Hectares
	Low brackish marsh replaced by:	
-2	Ponded water	2.3
-1	Non-vegetated	5.1
	Replaced by low brackish marsh:	
-1	High brackish marsh	31.9
-2	Oligohaline marsh	63.5
-3	Oligohaline marsh/scrub-shrub	6.5
-4	Scrub/shrub	5.9
-5	Forest	1.7
Total landward change associated with low brackish marsh		116.9
Total landward changes not associated with low brackish marsh		117.9

marsh were replaced by low brackish marsh (Table 3-5). Other notable landward changes included 11.5 ha of scrub-shrub replaced by high brackish marsh and 32.9 ha of oligohaline marsh/scrub-shrub replaced by oligohaline marsh.

The majority of vegetation changes attributed to seaward migration were related to increases in scrub-shrub and forest cover types, 254.8 and 182.8 ha, respectively (*i.e.*, excluding increases attributed to overland migration). The greatest amount of change of any combination occurred as 131.9 ha of oligohaline marsh were replaced by scrub-shrub, followed by 103.8 ha of scrub-shrub replaced by forest and 67.5 ha of oligohaline marsh/ scrub-shrub replaced by scrub-shrub.

The greatest individual changes occurred in the southwest corner of the study area (Figure 3-7). Although this area was undeveloped in 1998, it is evident that an attempt to convert the area to agricultural use was made. Though it appears that this attempt failed, considerable hydrologic alterations (*e.g.*, ditching and diking) were made and possibly contributed to the high degree of dynamism there. The majority of vegetation changes, regardless of direction, occurred closer to the landward margin than to the shoreline (Figure 3-7). This seemingly dynamic zone of change may draw attention to where the absolute landward margin of shorezone may be versus the potential landward margin that is depicted in the map. For example, at the plant community scale (Chapter 2), the landward margin of shorezone appeared to occur at elevations between 0.4 and 0.5 m above the lowest elevations of marsh. At transect O-2 in particular, the landward margin of shorezone (*e.g.*, Mixed marsh / *Morella* scrub margin boundary) measured approximately 0.46 m NAVD88 (tied to benchmark CAR98). This suggests that PSZ may be exaggerated by nearly 0.5 m in the vegetation map. Therefore, because the majority of change occurred near, but not at, the landward margin of PSZ, the areas of greater dynamics may be a consequence of the interface between sea level and terrestrial hydrology considerably below 1 m elevation.

It is important to note that the changes described above and in Table 3-5 represent gross changes; that is, they are not reduced by the changes in the opposite direction between the same cover types. Gross and net changes of individual cover type combinations may reflect within-combination dynamism. Of the 79 change combinations that occurred, 29 of these combinations were unidirectional, while 50 combinations exhibited changes in both directions. Table 3-7 illustrates the net area increase in any particular cover type while Table 3-8 illustrates the percent net increase of any particular change combination (*i.e.*, change in opposite direction not noted). The percentages in Table 3-8 may be used as a scale to reflect the within-combination degree of dynamism (100 = unidirectional change, 0 = opposing gross changes cancel each other). Thus, high values reflect less dynamism while lower values reflect greater dynamism. For example, where 32.9 ha of oligohaline marsh/scrub-shrub were replaced by oligohaline marsh in the landward direction (*i.e.*, loss of evergreen woody vegetation), 26.6 ha of oligohaline marsh were replaced by oligohaline marsh/scrub-shrub in a seaward direction (*i.e.*, increased evergreen woody vegetation) (Table 3-5). Therefore oligohaline marsh experienced a net gain of only 6.3 ha from oligohaline marsh/scrub-shrub (Table 3-7), which accounts for only 11% of the total change between the two cover types (Table 3-8). A simple conceptual diagram of this is presented in Figure 3-9.

Ponded water increased by 17% (2.6 ha) between 1958 and 1998. The majority of that increase involved conversion from low brackish marsh and was concentrated in one particular area southeast of NC Highway 12 (Figure 3-10, also see Figure 3-7 map inset).

Table 3-7. Net changes in potential shorezone vegetation. Change in opposite direction has been subtracted. Negative values not reported. Units in hectares.

From 1958: \ To 1998:	Estuarine water	Ponded water	Non-vegetated	Low brackish marsh	High brackish marsh	Oligohaline marsh	Oligohaline marsh/scrub-shrub	Scrub/shrub	Forest	Ditched low brackish marsh	Altered land	Non-shorezone	Net increase
Estuarine water										0.5	3.6		
Ponded water	0.3		0.2			0.0							
Non-vegetated	13.5				4.4	0.2		6.4	2.2	0.3	0.4		23.5
Low brackish marsh	72.3	2.2	3.0					8.0	0.6	114.2	5.5		132.7
High brackish marsh	0.0			20.7			10.9	24.0	11.0		0.7		51.1
Oligohaline marsh	0.7			46.5	8.5			121.4	16.3		73.9		260.1
Oligohaline marsh/scrub-shrub				5.3		6.3		67.5	37.7		1.2		107.0
Scrub/shrub	2.9								59.1	7.9	5.1		
Forest	5.4									0.0			
Ditched low brackish marsh													
Altered land									36.0	0.8			
Non-shorezone	9.7	0.3	0.5	0.5	3.4	0.8		18.8	200.6	0.1	24.7		259.4
Net increase	100.8	2.0						171.1	358.0	123.8	78.2		

Legend

- Converted estuarine water (erosion)
- Landward vegetation change
- No change
- Seaward vegetation change
- Converted to potential shorezone (migration)
- Anthropogenic changes

Table 3-8. Percent of within-combination change of potential shorezone vegetation as a measure of dynamism. Lower values equate to greater dynamism while higher values suggest greater unidirectional change.

From 1958: / To 1998:	Estuarine water	Ponded water	Non-vegetated	Low brackish marsh	High brackish marsh	Oligohaline marsh	Oligohaline marsh/scrub-shrub	Scrub/shrub	Forest	Ditched low brackish marsh	Altered land	Non-shorezone
Estuarine water										100	63	
Ponded water	98		100			100						
Non-vegetated	72				89	100		84	100	100	100	
Low brackish marsh	92	91	42					40	14	100	70	
High brackish marsh	50			48			100	53	82		100	
Oligohaline marsh	100			58	93			85	55		100	
Oligohaline marsh/scrub-shrub				70		11		100	91		100	
Scrub/shrub	100								40	100	67	
Forest	100									100		
Ditched low brackish marsh												
Altered land									42	100		
Non-shorezone	100	100	100	100	100	100		100	100	100	100	

Legend

- Converted estuarine water (erosion)
- Landward vegetation change
- No change
- Seaward vegetation change
- Converted to potential shorezone (migration)
- Anthropogenic changes

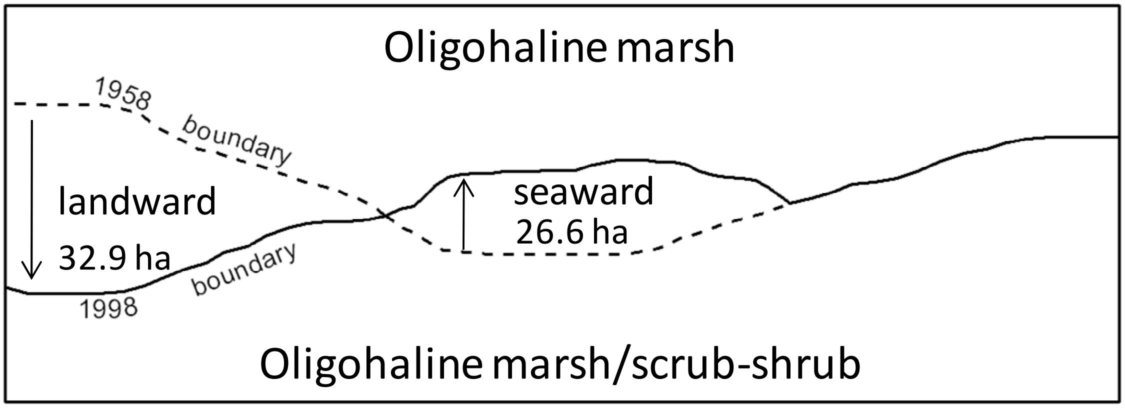
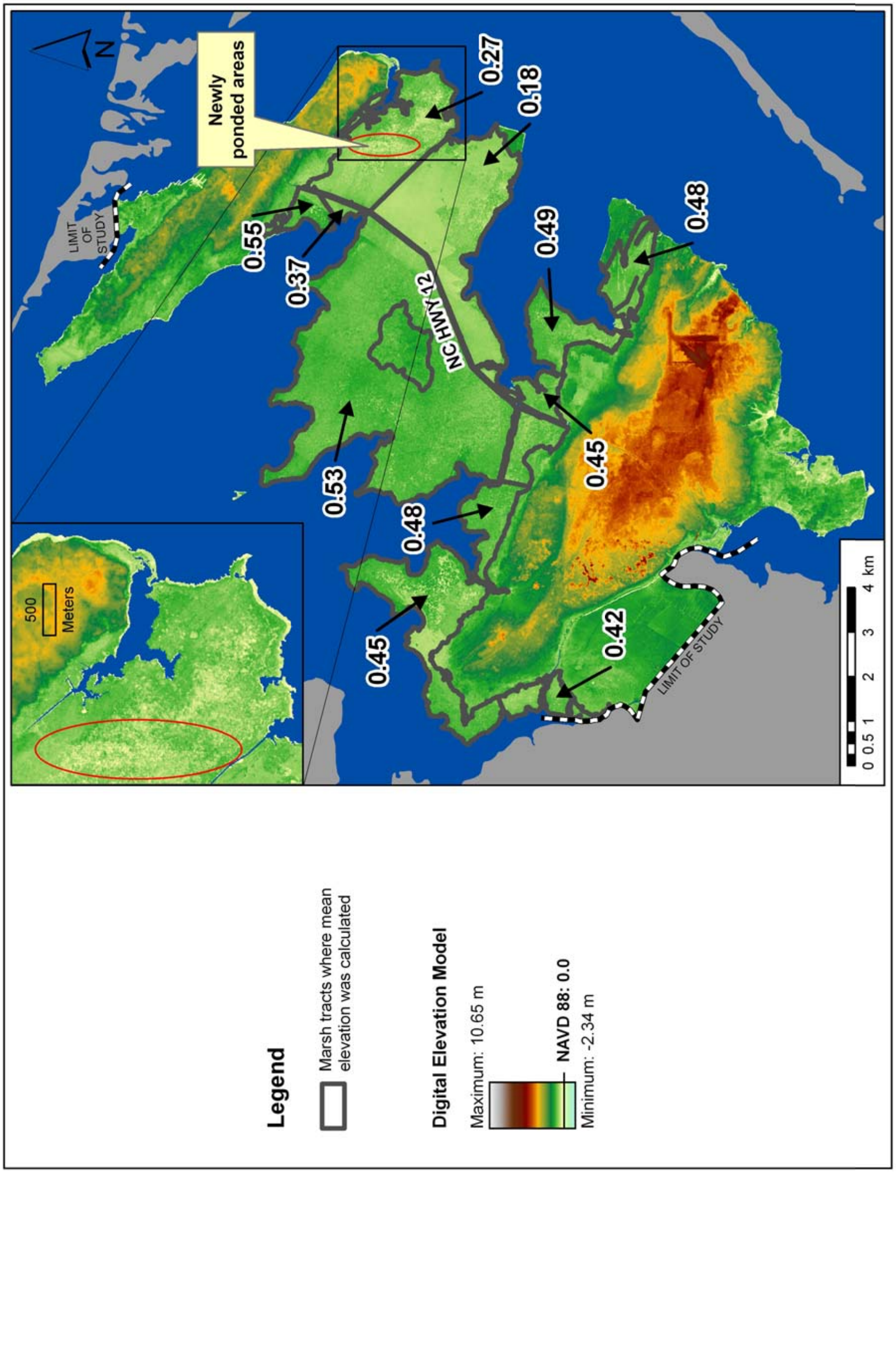


Figure 3-9. Conceptual diagram of opposing potential shorezone vegetation changes. Gross landward change of (32.9 ha) is reduced by gross seaward changes (26.6 ha) resulting in a within combination net landward gain of only 6.3 ha overall. Not to scale.

Figure 3-10. Eleven of the largest tracts of marsh surveyed for mean elevation using the DEM. Marshes situated east of NC HWY 12 in the northern portion of the map exhibit the lowest mean elevations 0.18 and 0.27 m. The map inset includes the location where ponded water increased by 2.3 ha between 1958 and 1998 (See Figure 3-6 for precise location of ponds). Figure is on following page.


Legend
Marsh tracts where mean elevation was calculated
Digital Elevation Model
Maximum: 10.65 m
NAVD 88: 0.0
Minimum: -2.34 m
Newly ponded areas
N
LIMIT OF STUDY
LIMIT OF STUDY
NC HWY 12
0.27
0.18
0.55
0.37
0.49
0.48
0.53
0.45
0.48
0.45
0.42
500
Meters
0 0.5 1 2 3 4 km

This conversion produced 10 irregularly shaped ponds situated in an interior portion of marsh.

Upon review of available remote sensing data prior to mapping, it became apparent that marshes southeast of NC Highway 12 were consistently darker than those west of the highway. NC Highway 12, constructed sometime prior to 1958, created a ~1 m high berm through Cedar Island marsh with the potential of altering its hydrology. The consistently darker reflectance of the eastern marsh may suggest lower density of plants (*e.g.*, exposed sediment resulting from reduce vegetative cover) and/or greater inundation. Using the DEM, mean elevations were calculated for 11 of the largest tracts of low brackish marsh (Figure 3-10). Results suggest that the two largest tracts east of NC Highway 12 exhibit the two lowest mean elevations (*e.g.*, 0.18 and 0.27 m NAVD 88). The size and density of ponds is also noticeably greater in these tracts than in others (Figure 3-7, inset). These observations may suggest that marshes southeast of NC Highway 12 are not vertically accreting at a pace comparable to rising sea-level.

Conclusion

This study builds the case for the press and pulse dynamics model (Bender *et al.* 1994). Here, sea-level rise is acting as a press on the shorezone and its landward margin, resulting in a relatively slow and gradual increase in inundation with collateral effects due to salinity. Storms, wild fires, clear cutting, or ditching cause abrupt biotic and abiotic changes, or pulses that drive rapid ecosystem change. Without the sustained press of rising sea level over time, areas subject to pulse-like disturbances would return to previous environmental conditions, and thus ecological communities, repeatedly. But because sea level is constantly rising, areas subject to these acute disturbances eventually reach a threshold at which point environmental conditions become so altered that the previous communities are lost or forced to migrate landward with shorezone being established at a new position (Poulter 2005).

This research demonstrates that over the past 40 years, shorezone vegetation has not migrated landward in concert with the transgression of PSZ itself. In fact, just the opposite appears to have occurred in the outer estuary. Despite the press of rising sea level, plant communities have either been restored to those prior to disturbance or have remained relatively stable. Areas that exhibited seaward change were presumably disturbed prior to 1958. Therefore, those earlier disturbances did not result in permanent vegetation change. In addition, seaward changes were primarily replaced by scrub-shrub and forest; both cover types are more closely associated with terrestrial conditions than the lower ranked cover types. These changes may be exemplary of ecosystem resiliency or resistance to environmental change (Brinson *et al.* 1995). However, they may also be exemplary of areas where environmental conditions were altered but returned to previous conditions, facilitating seaward migration and thus reestablishment of the original cover type. Likewise, landward migration of cover types observed here may not be permanent, particularly those mapped as scrub-shrub or forest in 1958. The plant communities present at that time may simply have been a consequence of short-term pulses in the preceding years or decades. The most likely factors are salt stress from storm surge flooding or fires, both of which can reduce dominance of woody plants. Future mapping of this study area is therefore required to capture changes that have occurred since 1998 and to form a stronger understanding of both the permanence and dynamism of shorezone vegetation change.

Synthesis

As sea level rises, the extent of shorezone is governed by the rate of migration at its landward margin, or leading edge, and the rate of erosion at its shoreline, or trailing edge, provided that the shorezone vertically accretes at a rate comparable to rising sea level. From a whole-estuary perspective (*i.e.*, a coarse scale analysis), shorezone wetland types systematically change according to their position along the estuarine gradient. Changes in landscape geomorphology and salinity are the basis for this pattern. Therefore, shorezone extent and type can be organized into a space-for-time framework of four temporal stages, each representing a few thousand years of landward migration of shorezone caused by rising sea level.

At the shorezone scale (*i.e.*, an intermediate scale analysis), cover types distinguishable in aerial photographs over decadal time scales were used to delineate vegetation patterns in an outer estuary shorezone. Changes in cover types did not conform to an overall tendency for landward migration, but rather demonstrated a dynamism unrelated to rising sea level.

At the plant community scale of analysis (*i.e.*, a fine scale), a hierarchical classification was constructed to encompass the two larger scales. Field-collected data identified plant communities that make up the coarser cover/wetland types illustrating a pattern of zonation that exists between the shoreline and the landward margin as well as between the outer and inner portions of the estuary. Plant community zonation can be explained principally by the salinity gradient, which itself is a component of the space-for-time framework.

These observations were made for the Neuse River estuary, a microtidal region with a geomorphic axis that runs along the larger sea-land gradient. It is not known whether this space-for-time framework is applicable to rising sea level and wetlands in other geomorphic settings.

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Appendix A

Transect Tables

Tables include plant communities, their distance from the shoreline and their width as observed along transects (indicated across top of table) and a complete list of plant species observed (along left margin of table). Species abundances are reported as percent cover of stratum below the community in which it was observed. Fire and wrack are indicated by 'p' for present. Elevation, microtopography, soil texture, soil porewater salinity, soil bulk-density, soil loss on ignition, and depth of peat are reported at the end of tables. Tables are arranged by transect, consisting of two pages each.

Sequence of tables and page numbers

Transect: I-1

	Shorezone Communities		
	S. cyno. marsh	*Morella* scrub swamp	*Morella* scrub swamp
dist. from shoreline (m)	0	53	104
width (m)	53	51	221
Herbaceous Stratum			
Spartina cynosuroides	81.7	0.4	
Typha latifolia	2.9	0.8	
Polygonum arifolium	0.8	0.4	
Alternanthera philoxeroides	0.5	31.3	
Sium suave	0.4	5.5	
Hibiscus moscheutos	0.4	0.4	
Ptilimnium capillaceum	0.3	0.2	
Carex comosa		12.5	
Osmunda regalis		8.8	25.4
Toxicodendron radicans		2.9	
Polygonum spp.		2.5	
Sagittaria latifolia		2.5	
Packera glabella		0.4	
Pontederia cordata		0.4	
Rumex spp.		0.4	
unidentified Poaceae spp.		0.1	
Rubus spp.			12.5
Cicuta maculata			2.5
Lyonia lucida			2.5
Morella cerifera			0.5
Hydrocotyle spp.			0.4
Juniperus virginiana			0.4
Lonicera japonica			0.4
Persea palustris			0.4
unidentified forb			0.4
Shrub Stratum			
Morella cerifera		38.6	69.2
Rosa palustris		3.8	
Toxicodendron radicans		3.8	
Acer rubrum		2.6	1.8
Berchemia scandens		1.3	
Vitis spp.			1.8
Persea palustris			0.9

Transect: I-1 (concluded)

	Shorezone Communities		
	S. cyno. marsh	*Morella* scrub swamp	*Morella* scrub swamp
dist. from shoreline (m)	0	53	104
width (m)	53	51	221
Tree Stratum			
Juniperus virginiana			3.8
Acer rubrum			2.8
Fraxinus carolinana			1.9
Persea palustris			0.3
Strata Summary			
herbaceous	87.0	69.5	45.5
shrub		50.0	73.8
tree			8.8
Evidence of disturbance			
fire			
wrack	p		
snags / ha		89	89
stumps / ha			44
large down wood / ha		89	221
Soil			
relative surface elevation (cm)	9	5	--
height of hummocks (cm)			
Description 0-30 cm	fibric peat	fibric peat	sapric peat
pore water salinity	1	1	0
bulk density (g/cm^3)	0.088	0.092	0.075
% organics	55.0	80.2	88.6
Description 30-60 cm	hemic peat	hemic peat	fibric peat
bulk density (g/cm^3)	0.094	0.094	0.098
% organics	72.1	87.5	86.8
Depth to mineral soil (cm)	265	230	200

Transect: I-2

	Shorezone Communities		
	Carex/ Baccharis/ Taxodium scrub	*Morella* scrub swamp	Mixed forest
dist. from shoreline (m)	0	58	110
width (m)	58	52	45
Herbaceous Stratum			
Carex comosa	81.7		
Rubus spp.	2.9		
Osmunda cinnamomea	0.8		
Ipomoea sagittata	0.1		
Alternanthera philoxeroides		53.0	
Hydrocotyle spp.		1.1	
Polygonum spp.		0.9	
unidentified forb		0.8	
Pontederia cordata		0.5	
Hibiscus moscheutos		0.4	
unidentified Caryophyllaceae spp.		0.1	
Convolvulus spp.		0.1	
Packera glabella		0.1	
Ranunculus spp.		0.1	
Rosa palustris		0.1	
Rumex spp.		0.1	
Sagittaria latifolia		0.1	
Arundinaria gigantea			5.0
Toxicodendron radicans			1.3
Lonicera japonica			0.7
Morella cerifera			0.4
Nyssa biflora			0.1
Peltandra virginica			0.1
Smilax rotundifolia			0.1
Shrub Stratum			
Morella cerifera	4.2	15.7	52.9
Toxicodendron radicans	1.5		12.3
Baccharis halimifolia	1.3	3.7	
Acer rubrum	1.0	1.9	1.4
Ampelopsis arborea	0.8		
Rosa palustris		2.2	
Juniperus virginiana		1.7	
Persea palustris		0.8	1.2
Ulmus americana		0.4	
Smilax rotundifolia			3.5
Lonicera japonica			2.3
Nyssa biflora			1.4

Transect: I-2 (concluded)

	Shorezone Communities		
	Carex/ Baccharis/ Taxodium scrub	*Morella* scrub swamp	Mixed forest
dist. from shoreline (m)	0	58	110
width (m)	58	52	45
Tree Stratum			
Taxodium distichum	6.3		
Acer rubrum	1.3		29.7
Salix spp.		1.3	
Nyssa biflora			22.4
Persea palustris			4.4
Morella cerifera			3.0
Pinus taeda			3.0
Strata Summary			
herbaceous	85.5	57.3	7.7
shrub	8.8	26.3	75.0
tree	7.5	1.3	62.5
Evidence of disturbance			
fire			
wrack			
snags / ha	266	89	89
stumps / ha	44	44	89
large down wood / ha	133	44	575
Soil			
relative surface elevation (cm)	8	3	--
height of hummocks (cm)			
Description 0-30 cm	sapric	hemic	black sand
pore water salinity	2	1	0
bulk density (g/cm^3)	0.074	0.095	0.321
% organics	58.9	69.5	44.8
Description 30-60 cm	sapric	hemic	sapric
bulk density (g/cm^3)	0.121	0.114	0.276
% organics	71.1	78.9	34.1
Depth to mineral soil (cm)	285	183	29

Transect: I-3

	Shorezone Communities				
	Cladium marsh	*Juncus* marsh	*Cladium* scrub	*Morella* scrub swamp	Mixed forest
dist. from shoreline (m)	0	28	46	71	86
width (m)	28	18	25	15	8
Herbaceous Stratum			0	0	
Cladium mariscus	99.2		66.7		
Mikania scandens	1.3				
Juncus roemerianus		84.2			
Osmunda cinnamomea		0.4		0.8	
Rosa palustris			0.8		
Polygonum spp.				34.2	
Hydrocotyle umbellata				2.2	
Morella cerifera				0.8	0.6
Osmunda regalis				0.8	
Ilex coriacea					2.5
Peltandra virginica					0.5
Juniperus virginiana					0.4
Pteridium aquilinum					0.1
Shrub Stratum					
Baccharis halimifolia			15.0	5.4	
Morella cerifera				26.8	67.0
Persea palustris				2.7	8.9
Juniperus virginiana				2.7	
Smilax spp.					5.4
Ilex coriacea					2.9
Toxicodendron radicans					2.3
Acer rubrum					1.0
Tree Stratum					
Nyssa biflora					51.5
Pinus taeda					15.2
Persea palustris					9.2
Acer rubrum					7.2
Liquidambar styraciflua					1.9
Strata Summary					
herbaceous	100.4	84.6	67.5	38.8	4.1
shrub			15.0	37.5	87.5
tree					85.0

Transect: I-3 (concluded)

	Shorezone Communities				
	Cladium marsh	*Juncus* marsh	*Cladium* scrub	*Morella* scrub swamp	Mixed forest
dist. from shoreline (m)	0	28	46	71	86
width (m)	28	18	25	15	8
Evidence of disturbance					
fire					
wrack					
snags / ha					44
stumps / ha					44
large down wood / ha					44
Soil					
relative surface elevation (cm)	21	22	30	36	47
height of hummocks (cm)	14	11	12	16	--
Description 0-30 cm	fibric peat	fibric peat	fibric peat	fibric peat	silty muck
pore water salinity	5	6	3	3	1
bulk density (g/cm^3)	0.102	0.093	0.076	0.060	0.068
% organics	56.5	68.0	66.5	80.9	87.5
Description 30-60 cm	fibric peat	fibric peat	fibric peat	fibric peat	silty muck
bulk density (g/cm^3)	0.184	0.156	0.106	0.090	0.068
% organics	49.8	60.5	78.2	81.6	87.2
Depth to mineral soil (cm)	125	130	180	140	120

Transect: I-4

	Shorezone Communities	
	Taxodium/ Nyssa swamp (shoreline)	*Taxodium/ Nyssa* swamp (interior)
dist. from shoreline (m)	0	23
width (m)	23	--
Herbaceous Stratum		
Polygonum arifolium	42.1	5.8
Pontederia cordata	21.7	
Alternanthera philoxeroides	14.3	
Polygonum spp.	11.0	
Phlox spp.	6.3	
Amaranthus cannabinus	0.4	
Polygonum sagittatum	0.4	
Osmunda regalis		17.1
Peltandra virginica		9.6
Saururus cernuus		9.2
Carex stricta		6.8
Cicuta maculata		2.9
Carex comosa		2.5
Itea virginica		2.5
Lobelia cardinalis		1.3
Boehmeria cylindrica		0.4
unidentified forb		0.4
Fraxinus carolinana		0.1
Mikania scandens		0.1
Shrub Stratum		
Fraxinus carolinana	7.5	29.8
Ulmus americana	0.3	
Morella cerifera		9.4
Itea virginica		5.6
Nyssa aquatica		4.3
Toxicodendron radicans		4.3
Ilex coriacea		4.0
Alnus spp.		1.3
Clethra alnifolia		1.3
Viburnum dentatum		1.3

Transect: I-4 (concluded)

	Shorezone Communities: *Taxodium/ Nyssa* swamp (shoreline)	*Taxodium/ Nyssa* swamp (interior)
dist. from shoreline (m)	0	23
width (m)	23	--
Tree Stratum		
Nyssa aquatica	23.1	13.1
Taxodium distichum	22.9	7.8
Nyssa biflora	4.1	15.7
Morella cerifera		13.3
Acer rubrum		13.0
Fraxinus carolinana		10.8
Strata Summary		
herbaceous	96.1	58.6
shrub	7.8	61.3
tree	50.0	73.8
Evidence of disturbance		
fire		
wrack		
snags / ha	89	
stumps / ha	89	44
large down wood / ha		89
Soil		
relative surface elevation (cm)	4	14
height of hummocks (cm)		11
Description 0-30 cm	fibric peat	sapric
pore water salinity	0	0
bulk density (g/cm^3)	0.269	0.151
% organics	32.5	52.5
Description 30-60 cm	fibric peat	hemic
bulk density (g/cm^3)	0.141	0.126
% organics	48.2	62.1
Depth to mineral soil (cm)	280	385

Transect: I-5

	Shorezone Communities			
	S. cyno./ Juncus marsh (levee)	*S. cyno./ Juncus* marsh	*Juncus* marsh	*Morella* scrub swamp
dist. from shoreline (m)	0	6	69	125
width (m)	6	63	62	--
Herbaceous Stratum				
Juncus roemerianus	57.1	61.7	100.0	10.4
Spartina cynosuroides	49.6	67.5		14.2
Polygonum spp.	1.7			
Iva frutescens	0.8			
Mikania scandens	0.4			
Erechtites hieracifolia	0.1			
Kosteletzkya virginica		0.8	0.8	
Ipomoea sagittata		0.2		
Typha angustifolia				7.1
Eleocharis spp.				2.5
Morella cerifera				0.8
Hydrocotyle spp.				0.4
Juncus coriaceus				0.4
Juniperus virginiana				0.4
Smilax rotundifolia				0.4
unidentified Poaceae spp.				0.4
Shrub Stratum				
Iva frutescens	15.0			
Morella cerifera				27.2
Persea palustris				6.6
Baccharis halimifolia				3.8
Tree Stratum				
Acer rubrum				14.1
Persea palustris				4.7
Juniperus virginiana				1.3
Strata Summary				
herbaceous	109.7	130.2	100.8	37.1
shrub	15.0			37.5
tree				20.0

Transcect: I-5 (concluded)

	Shorezone Communities			
	S. cyno./ Juncus marsh (levee)	*S. cyno./ Juncus* marsh	*Juncus* marsh	*Morella* scrub swamp
dist. from shoreline (m)	0	6	69	125
width (m)	6	63	62	--
Evidence of disturbance				
fire				
wrack				
snags / ha				
stumps / ha				44
large down wood / ha				266
Soil				
relative surface elevation (cm)	12	4	1	9
height of hummocks (cm)				
Description 0-30 cm	black sand	fibric peat	fibric peat	ric black sand
pore water salinity	9	7	10	6
bulk density (g/cm^3)	0.868	0.054	0.119	0.309
% organics	3.5	66.7	56.6	20.9
Description 30-60 cm	hemic	fibric peat	fibric peat	refusal
bulk density (g/cm^3)	0.231	0.203	0.278	--
% organics	21.7	22.5	25.1	--
Depth to mineral soil (cm)	160	110	80	25

Transect: I-6

	Shorezone Communities			
	S.cyno./ Juncus marsh (levee)	*S.cyno./ Juncus* marsh	*Cladium* scrub	Mixed forest
dist. from shoreline (m)	0	9	107	132
width (m)	9	98	25	--
Herbaceous Stratum				
Cladium mariscus	49.2		55.0	
Juncus roemerianus	31.3	50.0		
Spartina cynosuroides	17.1	56.3	10.4	
Panicum virgatum	0.4			
Polygonum spp.			14.6	
Smilax spp.			0.4	
Solidago sempervirens			0.4	
Morella cerifera			0.1	2.9
Persea palustris				1.3
Acer rubrum				0.2
unidentified Poaceae spp.				0.1
Shrub Stratum				
Iva frutescens	7.5			
Morella cerifera			53.6	5.4
Baccharis halimifolia			4.5	
Rosa palustris			4.5	
Ilex opaca				8.0
Persea palustris				3.1
Juniperus virginiana				2.7
Liquidambar styraciflua				0.4
Pinus taeda				0.4
Tree Stratum				
Liquidambar styraciflua			0.6	35.6
Pinus taeda			0.6	31.3
Acer rubrum				5.6
Persea palustris				1.3
Strata Summary				
herbaceous	97.9	106.3	80.9	4.4
shrub	7.5		62.5	20.0
tree			1.3	73.8

Transect: I-6 (concluded)

	Shorezone Communities			
	S.cyno./ Juncus marsh (levee)	*S.cyno./ Juncus* marsh	*Cladium* scrub	Mixed forest
dist. from shoreline (m)	0	9	107	132
width (m)	9	98	25	--
Evidence of disturbance				
fire				
wrack				
snags / ha				
stumps / ha				
large down wood / ha				
Soil				
relative surface elevation (cm)	23	6	9	28
height of hummocks (cm)				
Description 0-30 cm	black sand	hemic	fibric peat	black sand
pore water salinity	8	13	10	9
bulk density (g/cm^3)	1.008	0.070	0.426	0.928
% organics	1.7	67.6	41.1	5.5
Description 30-60 cm	fibric peat	fibric peat	black sand	refusal
bulk density (g/cm^3)	0.249	0.119	0.976	--
% organics	29.5	68.3	6.2	--
Depth to mineral soil (cm)	85	85	38	10

Transect: M-1

	Shorezone Communities		
	S. cyno./ Juncus marsh	*Morella* scrub margin	*P. taeda* forest
dist. from shoreline (m)	0	7	9
width (m)	7	2	--
Herbaceous Stratum			
Spartina cynosuroides	40.0		
Juncus roemerianus	16.7		
Iva frutescens	10.8		
Ruppia maritima	10.4		
Panicum virgatum	6.7	5.3	0.1
Cladium mariscus	5.0		
Lythrum lineare	2.5		
Juncus coriaceus		6.3	
Chasmanthium laxum		3.5	0.5
Solidago sempervirens		0.4	
Eupatorium serotinum		0.2	0.8
Smilax bona-nox		0.2	0.1
Nyssa biflora		0.2	
unidentified forb		0.1	2.5
Bignonia capreolata		0.1	0.1
Ilex opaca			6.3
Gaylussacia spp.			5.0
Cyrilla racemiflora			3.1
Carya tomentosa			2.5
Quercus alba			2.5
Smilax rotundifolia			0.5
unidentified Poaceae spp.			0.5
Hamamelis virginiana			0.4
Yucca filamentosa			0.4
Liquidambar styraciflua			0.1
Smilax laurifolia			0.1
Shrub Stratum			
Iva frutescens	8.8		
Morella cerifera		74.0	12.0
Nyssa biflora		9.9	7.0
Cyrilla racemiflora		1.1	11.7
Acer rubrum			7.2
Liquidambar styraciflua			7.2
Alnus spp.			2.4
Carya tomentosa			2.4

Transect: M-1 (concluded)

	Shorezone Communities		
	S. cyno./ Juncus marsh	*Morella* scrub margin	*P. taeda* forest
dist. from shoreline (m)	0	7	9
width (m)	7	2	--
Tree Stratum			
Liquidambar styraciflua		1.3	
Pinus taeda			33.9
Nyssa biflora			8.7
Liriodendron tulipifera			7.4
Strata Summary			
herbaceous	92.1	16.1	25.4
shrub	8.8	85.0	50.0
tree		1.3	50.0
Evidence of disturbance			
fire			
wrack			
snags / ha			
stumps / ha	44	44	
large down wood / ha			133
Soil			
relative surface elevation (cm)	34	91	184
height of hummocks (cm)			
Description 0-30 cm	sandy peat	cay sand	sand loam
pore water salinity	11	0	0
bulk density (g/cm^3)	0.178	1.180	1.046
% organics	25.4	1.9	2.8
Description 30-60 cm	sand	refusal	refusal
bulk density (g/cm^3)	0.678	--	--
% organics	6.1	--	--
Depth to mineral soil (cm)	30	0	0

Transect: M-2

	Shorezone Communities		
	S. cyno./ Juncus marsh	*Cladium* marsh	*Persea* forest
dist. from shoreline (m)	0	11	47
width (m)	11	25	47
Herbaceous Stratum			
Juncus roemerianus	61.7		
Samolus valerandi	15.0	2.5	
Spartina cynosuroides	14.2		
unidentified forb	5.3		
Hibiscus moscheutos	5.0	17.5	
Cladium mariscus		89.2	
Osmunda regalis		0.8	6.3
Saururus cernuus			6.3
Ptilimnium capillaceum			2.5
Hydrocotyle umbellata			0.5
Baccharis halimifolia			0.4
Cicuta maculata			0.4
Hydrocotyle spp.			0.4
Juniperus virginiana			0.4
Mikania scandens			0.4
Morella cerifera			0.4
Woodwardia virginica			0.4
Berchemia scandens			0.1
Polygonum spp.			0.1
Toxicodendron radicans			0.1
Shrub Stratum			
Morella cerifera			34.2
Berchemia scandens			11.6
Juniperus virginiana			9.7
Persea palustris			5.8
Tree Stratum			
Persea palustris			40.3
Acer rubrum			9.7
Juniperus virginiana			8.9
Morella cerifera			2.3
Strata Summary			
herbaceous	101.2	110.0	18.7
shrub			61.3
tree			61.3

Transect: M-2 (concluded)

	Shorezone Communities		
	S. cyno./ Juncus marsh	*Cladium* marsh	*Persea* forest
dist. from shoreline (m)	0	11	47
width (m)	11	25	47
Evidence of disturbance			
fire			
wrack			
snags / ha			44
stumps / ha			44
large down wood / ha			398
Soil			
relative surface elevation (cm)	5	4	26
height of hummocks (cm)			
Description 0-30 cm	fibric peat	fibric peat	fibric peat
pore water salinity	6	2	2
bulk density (g/cm^3)	0.108	0.077	0.100
% organics	61.1	52.2	84.5
Description 30-60 cm	fibric peat	fibric peat	fibric peat
bulk density (g/cm^3)	0.111	0.109	0.127
% organics	69.7	78.6	83.9
Depth to mineral soil (cm)	430	390	300

Transect: M-3

	Shorezone Communities		
	Juncus marsh	*Cladium/ Taxodium* marsh	*Taxodium/ Nyssa* swamp
dist. from shoreline (m)	0	22	29
width (m)	22	7	107
Herbaceous Stratum			
Juncus roemerianus	79.2	0.5	
Amaranthus cannabinus	6.3		
Hibiscus moscheutos	5.0	6.3	
Solidago sempervirens	0.1		2.5
Cladium mariscus		61.3	
Ipomoea sagittata		27.1	
Panicum virgatum		6.3	
Osmunda regalis			7.9
Juncus coriaceus			6.3
unidentified forb			2.5
Morella cerifera			0.9
Juniperus virginiana			0.4
Persea palustris			0.1
Polygonum spp.			0.1
Smilax laurifolia			0.1
Smilax rotundifolia			0.1
Shrub Stratum			
Toxicodendron radicans	1.3	2.1	
Taxodium distichum		0.4	
Morella cerifera			31.9
Juniperus virginiana			24.8
Persea palustris			14.2
Acer rubrum			7.1
Bignonia capreolata			3.5
Pinus taeda			3.5
Tree Stratum			
Taxodium distichum	1.3	34.4	39.6
Juniperus virginiana		3.1	
Pinus taeda			12.2
Ulmus americana			6.2
Nyssa biflora			6.0
Persea palustris			5.3
Acer rubrum			4.4

Transect: M-3 (concluded)

	Shorezone Communities		
	Juncus marsh	*Cladium/ Taxodium* marsh	*Taxodium/ Nyssa* swamp
dist. from shoreline (m)	0	22	29
width (m)	22	7	107
Strata Summary			
herbaceous	90.5	101.3	20.8
shrub	1.3	2.5	85.0
tree	1.3	37.5	73.8
Evidence of disturbance			
fire			
wrack	p		
snags / ha	133	44	89
stumps / ha	44		177
large down wood / ha	44	89	133
Soil			
relative surface elevation (cm)	19	18	25
height of hummocks (cm)			21
Description 0-30 cm	fibric peat	fibric peat	k brown(dark)
pore water salinity	12	10	8
bulk density (g/cm^3)	0.200	0.139	0.080
% organics	39.9	60.4	61.9
Description 30-60 cm	hemic brown	fibric peat	k brown(dark)
bulk density (g/cm^3)	0.235	0.183	0.144
% organics	19.1	45.1	56.8
Depth to mineral soil (cm)	140	200	130

Transect: O-1

	Shorezone Communities						
	S. alt. fringe	*Juncus* marsh	Interior mixed marsh	*Cladium* marsh	Morella scrub/ Ghost forest	*Morella* scrub swamp	Mixed forest
dist. from shoreline (m)	0	1	381	578	906	1024	1214
width (m)	1	380	197	328	118	190	--
Herbaceous Stratum							
Spartina alterniflora	81.7						
Juncus roemerianus		93.3	7.9				
Spartina patens		2.9	64.2				
Borrichia frutescens		0.4					
Kosteletzkya virginica		0.2					
Distichlis spicata			22.9				
Iva frutescens			2.9				
Fimbristylis castanea			0.4				
Cladium mariscus				100.0	2.5	2.5	
Rubus spp.				0.2	20.0		0.1
Apios americana				0.2			
Boehmeria cylindrica				0.1			
Ipomoea sagittata				0.1			
Osmunda cinnamomea					20.4		5.4
Osmunda regalis					3.4		0.4
Toxicodendron radicans					3.0	0.1	
Morella cerifera					2.9	0.4	2.6
Erechtites hieracifolia					2.5		
Mikania scandens					0.5	0.1	
Ilex vomitoria					0.4		
Acer rubrum					0.1		0.3
Lemna minor						10.8	
Typha latifolia						9.2	
Lyonia lucida						6.3	0.4
Hydrocotyle umbellata						0.5	
Polygonum spp.						0.5	
Bacopa monnieri						0.1	
Rosa palustris						0.1	
Salix spp.						0.1	
Solidago sempervirens						0.1	
Carex spp.							10.4
Leucothoe axillaris							6.3
Persea palustris							2.9
Gelsemium sempervirens							0.8
Eupatorium serotinum							0.4
Smilax laurifolia							0.4
Pinus taeda							0.3
Fraxinus spp.							0.1
Smilax bona-nox							0.1

Transect: O-1 (concluded)

	Shorezone Communities						
	S. alt. fringe	*Juncus* marsh	Interior mixed marsh	*Cladium* marsh	Morella scrub/ Ghost forest	*Morella* scrub swamp	Mixed forest
dist. from shoreline (m)	0	1	381	578	906	1024	1214
width (m)	1	380	197	328	118	190	--
Shrub Stratum							
Baccharis halimifolia				0.2			
Acer rubrum				0.2	4.8		2.7
Morella cerifera				0.1	17.5	36.1	9.2
Toxicodendron radicans				0.1			
Pinus taeda					16.5	22.2	
Persea palustris						7.7	1.3
Lyonia lucida						5.1	0.5
Juniperus virginiana						2.6	
Gaylussacia spp.							0.8
Fraxinus carolinana							0.5
Tree Stratum							
Pinus taeda					5.5	4.5	14.5
Morella cerifera					4.5	2.8	
Nyssa biflora					3.4		10.6
Nyssa aquatica					2.7		
Persea palustris					2.0	1.5	2.1
Acer rubrum					1.9		21.7
Liquidambar styraciflua							24.7
Quercus nigra							6.7
Liriodendron tulipifera							4.7
Strata Summary							
herbaceous	81.7	96.8	98.3	100.5	55.8	30.8	30.8
shrub				0.5	38.8	73.8	15.0
tree					20.0	8.8	85.0
Evidence of disturbance							
fire				p			
wrack		p		p			
snags / ha					133	221	44
stumps / ha				89	89	44	
large down wood / ha					310	44	177
Soil							
relative surface elevation (cm)	--	--	--	--	--	--	--
height of hummocks (cm)				18		23	
Description 0-30 cm	silty muck	fibric peat	fibric peat	fibric peat	fibric peat	fibric peat	black sand
pore water salinity	24	22	16	4	0	3	1
bulk density (g/cm^3)	0.435	0.140	0.125	0.085	0.050	0.140	0.760
% organics	16.5	43.1	66.3	86.3	81.5	50.7	6.5
Description 30-60 cm	silty muck	hemic	hemic	fibric peat	fibric peat	sapric muck	refusal
bulk density (g/cm^3)	0.385	0.170	0.115	0.120	0.110	0.240	--
% organics	18.8	32.9	54.3	69.9	64.5	20.0	--
Depth to mineral soil (cm)	160	115	80	92	79	58	0

Transect: O-2

	Shorezone Communities				
	S. alt. fringe	Levee mixed marsh	*S. alt./ Juncus* marsh	Interior mixed marsh	*Morella* scrub margin
dist. from shoreline (m)	0	2	7	206	219
width (m)	2	5	199	13	9
Herbaceous Stratum					
Spartina alterniflora	62.5		32.8		
Spartina patens		31.9	1.7	23.3	
Borrichia frutescens		5.6			
Iva frutescens		4.4		3.3	
Solidago sempervirens		1.3		0.4	
Juncus roemerianus			13.1	0.4	
Salicornia depressa			2.0		
Distichlis spicata			0.6	6.3	
Fimbristylis castanea				29.2	
Eleocharis spp.				17.5	10.4
Ipomoea sagittata				14.2	8.8
Kosteletzkya virginica				0.5	
Parthenocissus quinquefolia					9.3
Mikania scandens					6.3
Rubus spp.					5.4
Smilax bona-nox					3.0
Juncus coriaceus					2.5
unidentified Poaceae spp.					2.5
Toxicodendron radicans					0.5
Eupatorium serotinum					0.4
Ampelopsis arborea					0.1
Rumex spp.					0.1
Shrub Stratum					
Morella cerifera					73.5
Pinus serotina					9.2
Smilax bona-nox					1.1
Smilax rotundifolia					1.1
Tree Stratum					
Salix spp.					5.6
Ulmus americana					1.9
Pinus serotina					1.3
Strata Summary					
herbaceous	62.5	43.2	50.1	95.1	49.3
shrub					85.0
tree					8.8

Transect: O-2 (concluded)

	Shorezone Communities				
	S. alt. fringe	Levee mixed marsh	*S. alt./ Juncus* marsh	Interior mixed marsh	*Morella* scrub margin
dist. from shoreline (m)	0	2	7	206	219
width (m)	2	5	199	13	9
Evidence of disturbance					
fire	Area disturbed by fire four months prior				
wrack					
snags / ha					44
stumps / ha					
large down wood / ha					575
Soil					
relative surface elevation (cm)	11	41	13	30	78
height of hummocks (cm)					
Description 0-30 cm	fibric peat	sand	fibric peat	black sand	refusal
pore water salinity	33	7	30	10	1
bulk density (g/cm^3)	0.415	0.415	0.274	0.594	--
% organics	18.8	18.8	27.7	10.5	--
Description 30-60 cm	silty muck	silty muck	fibric peat	gray sand	refusal
bulk density (g/cm^3)	0.337	0.337	0.586	1.287	--
% organics	29.6	29.6	19.8	1.3	--
Depth to mineral soil (cm)	200	230	113	21	0

Transect: O-3

	Shorezone Communities				
	Levee mixed marsh	*Juncus* marsh	Interior mixed marsh (herb)	Interior mixed marsh (shrub)	*P. serotina* scrub
dist. from shoreline (m)	0	29	472	538	592
width (m)	29	443	66	54	--
Herbaceous Stratum					
Spartina patens	41.7			37.5	10.8
Iva frutescens	22.1				
Fimbristylis castanea	18.8		10.8	0.8	
Distichlis spicata	12.5	0.1	45.8		
Solidago sempervirens	0.4			6.7	
unidentified liana	0.4				
Juncus roemerianus		37.5	18.3		
Panicum virgatum				17.5	
Morella cerifera				5.0	6.3
Pluchea odorata				5.0	
Ipomoea sagittata				1.7	
Rubus spp.				0.8	10.4
Baccharis halimifolia				0.8	
Setaria parviflora				0.8	
Osmunda regalis					34.6
Carex spp.					12.5
Carex glaucescens					6.7
Eupatorium serotinum					5.4
Chasmanthium laxum					0.4
Pinus serotina					0.4
unidentified forb					0.4
Shrub Stratum					
Iva frutescens	38.8				
Morella cerifera				1.9	
Baccharis halimifolia				0.6	
Persea palustris					16.5
Pinus serotina					13.8
Liquidambar styraciflua					13.4
Acer rubrum					3.1
Ilex vomitoria					3.1

Transect: O-3 (concluded)

	Shorezone Communities				
	Levee mixed marsh	*Juncus* marsh	Interior mixed marsh (herb)	Interior mixed marsh (shrub)	*P. serotina* scrub
dist. from shoreline (m)	0	29	472	538	592
width (m)	29	443	66	54	--
Strata Summary					
herbaceous	95.8	37.6	75.0	76.7	87.9
shrub	38.8			2.5	50.0
tree					26.3
Evidence of disturbance					
fire	Area disturbed by fire six months prior				
wrack					
snags / ha				89	44
stumps / ha				443	133
large down wood / ha				266	133
Soil					
relative surface elevation (cm)	21	3	19	32	61
height of hummocks (cm)					
Description 0-30 cm	brown sand	fibric peat	ric black sand	ric black sand	black sand
pore water salinity	5	22	27	9	3
bulk density (g/cm^3)	1.200	0.093	0.409	0.601	0.760
% organics	0.9	57.1	17.4	17.5	10.9
Description 30-60 cm	refusal	hemic	black sand	refusal	refusal
bulk density (g/cm^3)	--	0.319	0.901	--	--
% organics	--	38.2	--	--	--
Depth to mineral soil (cm)	170	80	25	10	8

Appendix B

Additional ordination results

Table B-1. DCA ordination data summary and "after-the-fact" test.

```
Total variance ("inertia") in the species data:   8.3095

Eigenvalues
Axis 1:   0.945
Axis 2:   0.601
Axis 3:   0.486


"After-the-fact" test
PC-ORD 5.10
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Coefficients of determination for the correlations between
ordination
distances and distances in the original n-dimensional space:

            R Squared
Axis   Increment   Cumulative
 1       .147        .147
 2      -.014        .132
 3      -.005        .127

Increment and cumulative R-squared were adjusted for any lack
of orthogonality of axes.

Axis pair     r     Orthogonality,% = 100(1-r^2)
  1 vs 2     0.480     77.0
  1 vs 3    -0.040     99.8
  2 vs 3    -0.101     99.0

Number of entities = 47
Number of entity pairs used in correlation = 1081
Distance measure for ORIGINAL distance: Euclidean
(Pythagorean)
```

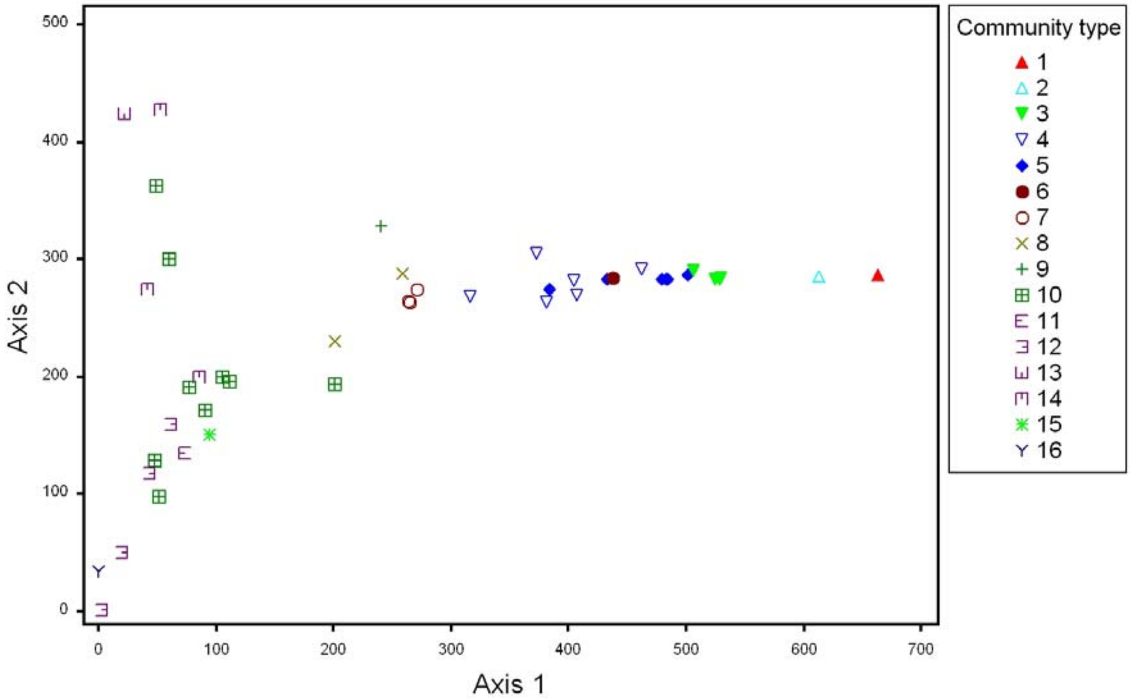

Figure B-1. DCA ordination labeled according to community type. Numbers correspond to the community types described below.

<u>Key</u>

1 - *Spartina alterniflora* fringe
2 - *Spartina alterniflora*/*Juncus* marsh
3 - *Juncus* marsh
4 - *Spartina cynosuroides*/*Juncus* marsh
5 - Mixed marsh (levee/interior)
6 - *Spartina cynosuroides* marsh
7 - *Cladium* marsh
8 - *Cladium* scrub
9 - *Cladium*/Taxodium scrub
10 - *Morella* scrub (swamp/ghost forest/margin)
11 - *Persea* forest
12 - *Mixed* forest
13 - *Carex/Baccharis/Taxodium* scrub
14 - *Taxodium/Nyssa* swamp
15 - *Pinus serotina* scrub
16 - *Pinus taeda* forest

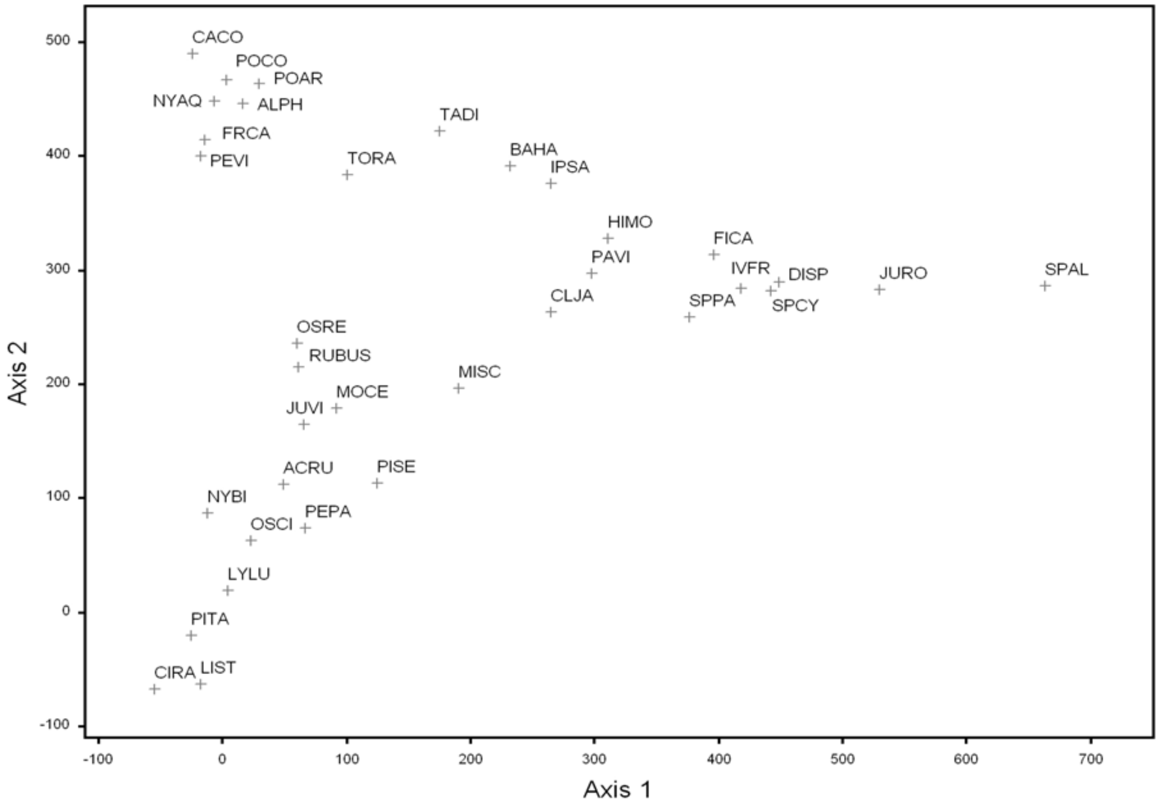

Figure B-2. DCA ordination species plot. Species are labeled according to the first two letters of the genus and species names. See key to codes below.

<u>Key</u>

ACRU	*Acer rubrum*	NYAQ	*Nyssa aquatica*
ALPH	*Alternanthera philoxeroides*	NYBI	*Nyssa biflora*
BAHA	*Baccharis halimifolia*	OSCI	*Osmunda cinnamome*
CACO	*Carex comosa*	OSRE	*Osmunda regalis*
CIRA	*Cicuta maculata*	PAVI	*Panicum virgatum*
CLJA	*Clethra alnifolia*	PEPA	*Persea palustris*
DISP	*Distichlis spicata*	PEVI	*Peltandra virginica*
FICA	*Eupatorium serotinum*	PISE	*Pinus serotina*
FRCA	*Fraxinus carolinana*	PITA	*Pinus taeda*
HIMO	*Hibiscus moscheutos*	POAR	*Polygonum arifolium*
IPSA	*Ipomoea sagittata*	POCO	*Pontederia cordata*
IVFR	*Iva frutescens*	RUBUS	*Rosa palustris*
JURO	*Juncus roemerianus*	SPAL	*Spartina alterniflora*
JUVI	*Juniperus virginiana*	SPCY	*Spartina cynosuroide*
LIST	*Liquidambar styraciflua*	SPPA	*Spartina patens*
LYLU	*Lyonia lucida*	TADI	*Taxodium distichum*
MISC	*Mikania scandens*	TORA	*Toxicodendron radic*
MOCE	*Morella cerifera*		

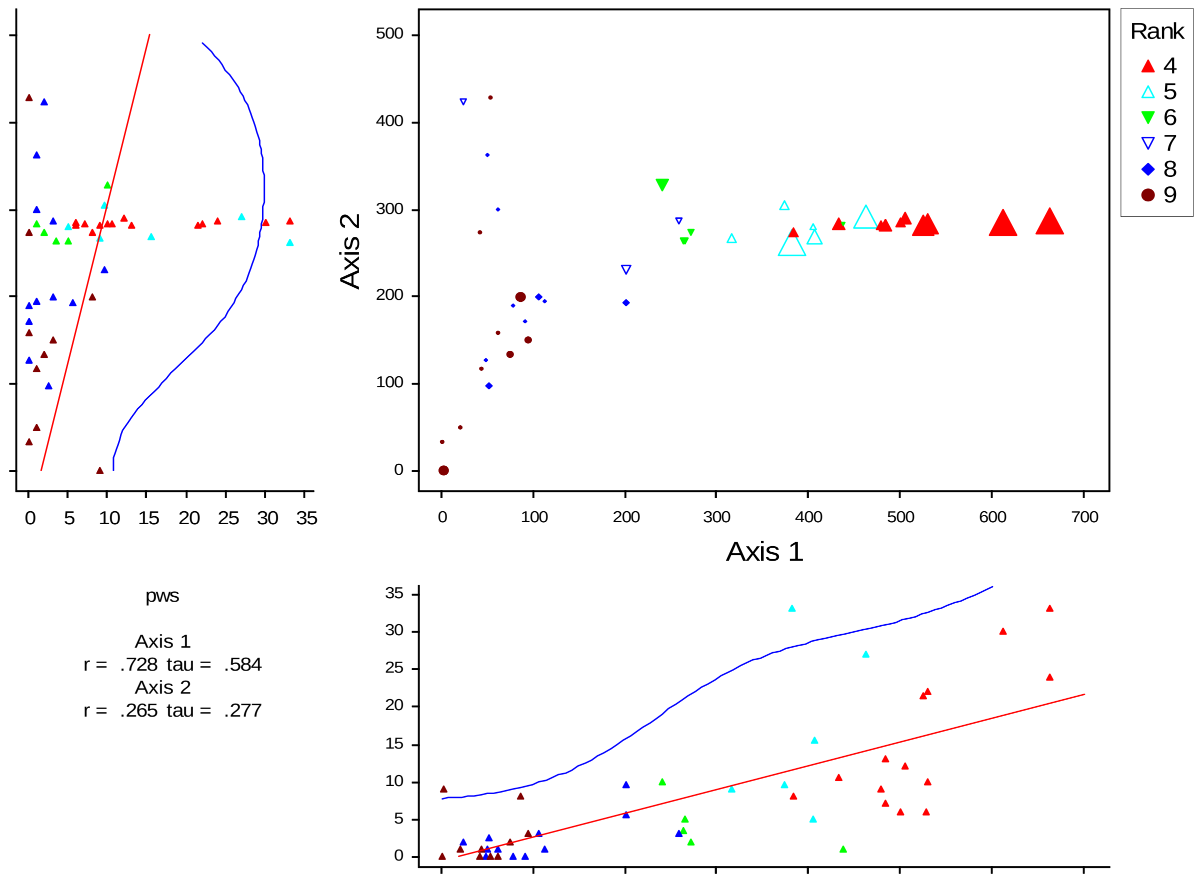

Figure B-3. Correlations of ordination axis scores with soil porewater salinity (pws) measurements. The strong positive correlation (r = 0.728) between soil pore water salinity and axis 1 scores likely explain zonation of shorezone vegetation.

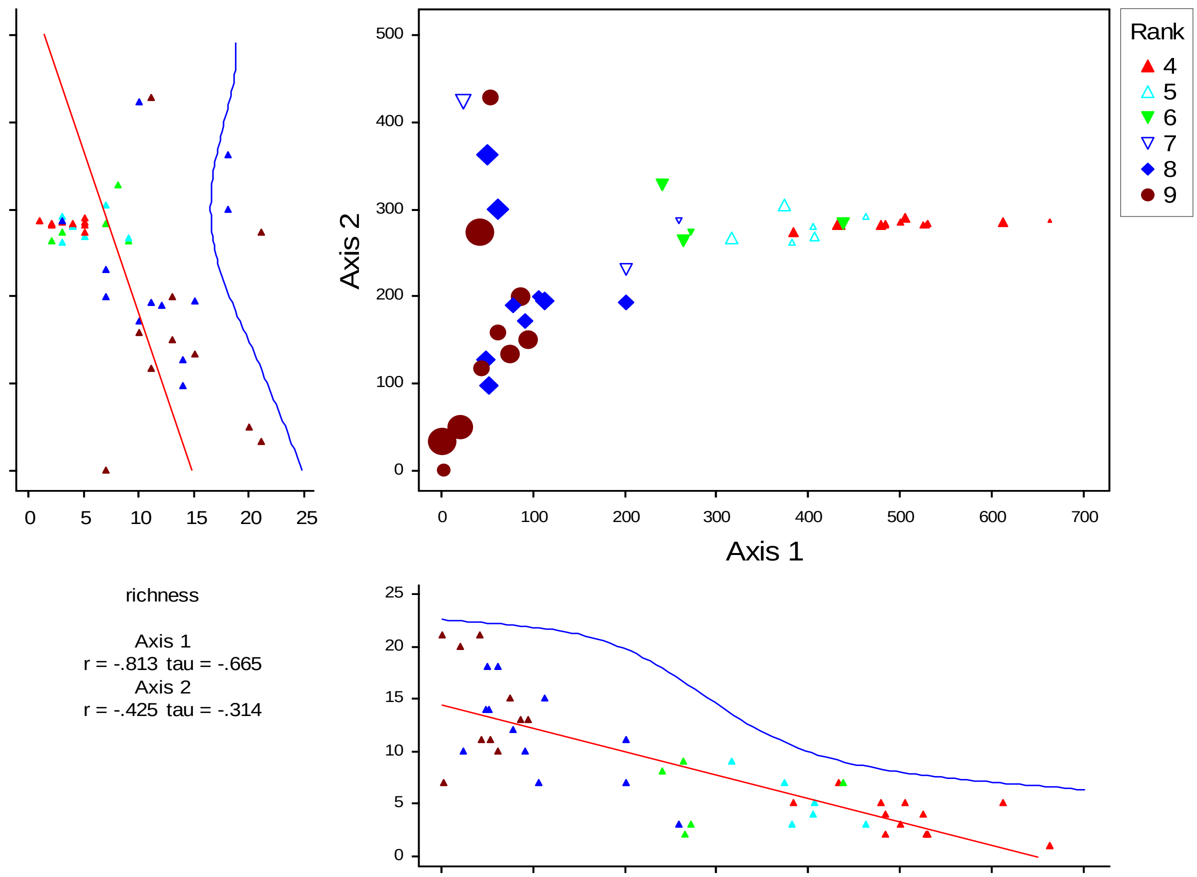

Figure B-4. Species richness correlation with axis 1. Correlations of ordination axis scores with species richness of samples, a passive variable. The strong negative correlation (r =-0.813) between species richness and axis 1 scores is likely a result of soil porewater salinity.

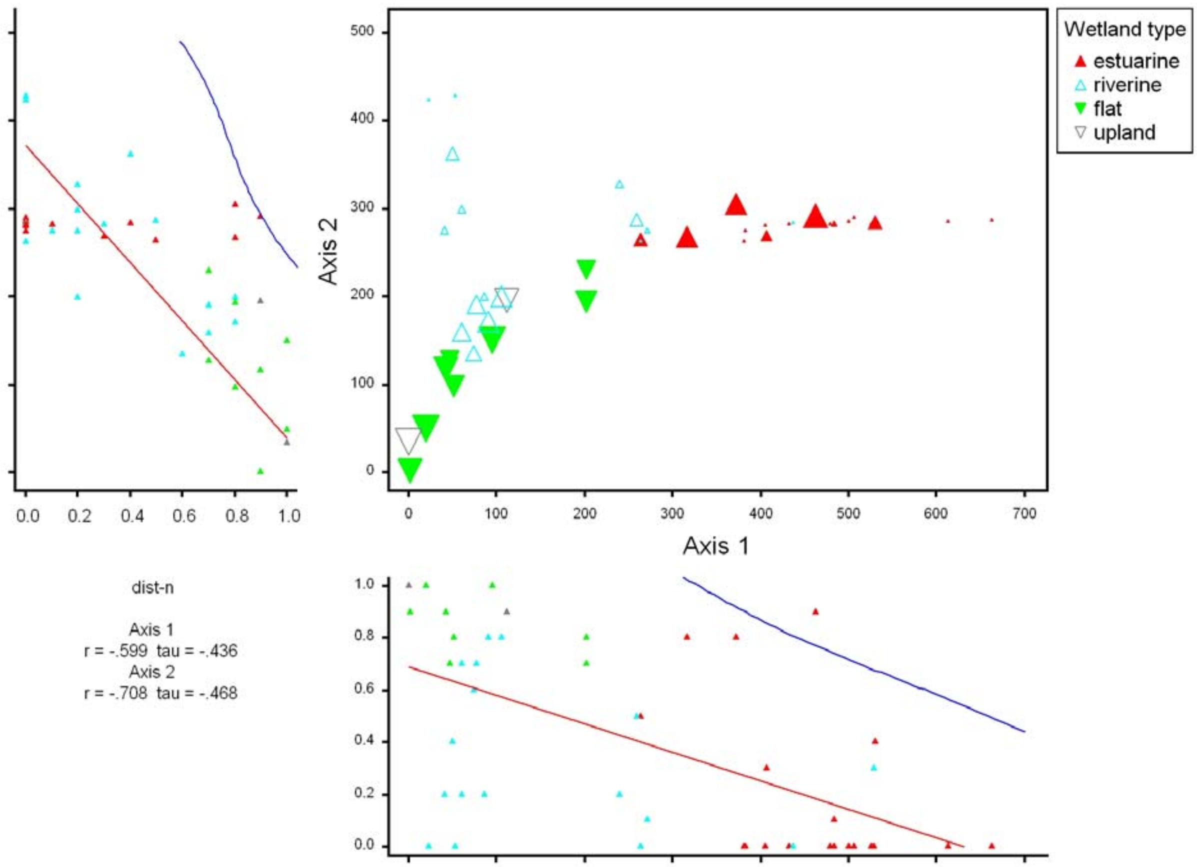

Figure B-5. Correlations of ordination axis scores with normalized distance from shoreline (dist-n). The negative correlation (r =-0.708) between distance from shoreline and axis 2 scores is consistent with the findings of Chapter 1 in that flat wetlands, toward the bottom of axis 2, were not present at the shoreline.

Biography

David M. Kunz was born on September 10th, 1974 in Dover, New Jersey. He grew up in the small suburban town of Hopatcong nestled in the Highlands physiographic province of New Jersey. He graduated from Hopatcong High School in 1993 and enrolled at County College of Morris where he discovered his interest in environmental science. While at community college he was named a Scholar Athlete by the National Junior College Athletic Association while playing for the school's ice hockey team, the Titans. In 1995, David hung up his skates and transferred to Cook College, Rutgers University to purse a Bachelor of Science, majoring in Environmental Planning and Design. In his last year of college he fulfilled his desire to complete a course in field ecology. He credits this experience and the enthusiastic teaching style of his professor Dr. Roger Locandro with inspiring his motivation to study ecology and natural resource management.

Upon graduating from Cook College in 1998, David spent three months volunteering for a Ph.D. candidate conducting forestry research in the vicinity of the Copper River Delta, Alaska. He then embarked on a career in environmental consulting where he was introduced to wetland science. While working for URS Corporation, he participated in the largest privately funded wetland restoration project in the world at the time, the PSEG-Estuary Enhancement Program in the Delaware Bay estuary. He later accepted a position to work for Edwards and Kelcey Inc. as a wetland and environmental specialist where he contributed to multiple environmental impact statements for various railway improvement and expansion projects. Motivated by his interest in wetland science, in 2005 David enrolled in graduate school with the Department of Biology at East Carolina University to study wetland ecology.

David married his wife Kathryn Ann Albrecht on July 31st, 2004. They shared the birth to their first son, Nathaniel Oliver on May 22nd, 2008. He and his family plan to return to New Jersey were he was offered a position to work as a consulting botanist with the New Jersey Department of Environmental Protection, Division of Land Use Regulation.

Photo of David surveying a *Morella* scrub community along transect O-1 in November of 2006. Photo by M. Brinson.