Lisa D. Ricker. **RESISTANCE TO STATE CHANGE BY COASTAL ECOSYSTEMS UNDER CONDITIONS OF RISING SEA LEVEL** (Under the direction of Dr. Mark M. Brinson) Department of Biology. May 1999.

The mainland fringe of the Virginia Coast Reserve was characterized to establish patterns useful in predicting where ecosystem state change is most likely to occur in response to rising sea level. State change is the conversion from one ecosystem class (state) to another. Characterization of patterns took place at two scales: (1) a broad scale (10's of kilometers) that separated the mainland into three geographic regions (south, central, north) by using topographic and soil maps, and (2) a smaller scale (10's of meters) applicable to state change that separated field sites into four ecosystem states (forest, forest-marsh transition, high marsh, low marsh). Small scale patterns were established through a four step process. First, ecosystem states were characterized by their soils, vegetation, and elevation. Next, sites within ecosystem states were classified into three resistance groups (low, intermediate, high) according to physical attributes likely to affect their resistance to state change. These included slope, elevation, and soil drainage class. Resistance groups were then compared to determine if they were currently in different stages of state change. Fourth, map and field indicators were identified for the three forest resistance groups.

At the broad scale, the central geographic region had the most land area available for forest conversion to marsh, while the north and south regions had little area available for this state change. On a smaller scale, ecosystem changes that occurred with each seaward state included a decline in vegetation species richness and structural complexity, and an increase in organic matter and soil salinity. Low resistance forest sites appeared to

be in a more advanced stage of state change than intermediate or high resistance forests because they most closely resembled transitions. The three forest resistance groups were identifiable on maps by soil types and landforms, and in the field by zone width, species dominance, slope, and elevation. Based on these indicators, a procedure was developed to identify forest locations most likely to convert to marsh, given a 15 cm rise in sea level.

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RESISTANCE TO STATE CHANGE

BY COASTAL ECOSYSTEMS

UNDER CONDITIONS OF RISING SEA LEVEL

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TABLE OF CONTENTS

LIST OF FIGURES....................v

LIST OF TABLES....................ix

1. INTRODUCTION....................1

2. SITE DESCRIPTION....................10

3. METHODS....................15

3.1 Megasite Characterization....................15

3.2 Ecosystem State Characterization....................20

3.3 Ecosystem State Classification....................29

3.4 Characterization and Comparison of Resistance Groups....................32

3.5 Identification of Map and Field Indicators of Resistance Groups....................34

4. RESULTS....................36

4.1 Megasite Characterization....................36

4.2 Ecosystem State Characterization....................45

4.3 Ecosystem State Classification....................82

4.4 Resistance Group Comparison....................93

4.5 Resistance Group Map and Field Indicators....................110

5. DISCUSSION....................123

5.1 Outlook for Three Geographic Regions of Megasite....................123

5.2 Ecosystem State Characteristics....................126

5.3 Causes of State Change....................130

5.4 Resistance Group Classification....................132

5.5 Stages of State Change for Resistance Groups....................135

5.6 Seaward States of Forest Resistance Groups....................140

5.7 Map and Field Indicators of Forest Resistance Groups....................142

5.8 Coastal Forest Resistance Classification Procedure....................150

LITERATURE CITED..155

APPENDIX A. AVERAGE LOW MARSH PERCENT COVER................................161

APPENDIX B. AVERAGE HIGH MARSH PERCENT COVER...............................164

APPENDIX C. AVERAGE TRANSITION PERCENT COVER................................169

APPENDIX D. AVERAGE FOREST PERCENT COVER..176

APPENDIX E. HIGH MARSH WOODY SPECIES DENSITY.................................185

APPENDIX F. TRANSITION WOODY SPECIES DENSITY AND BASAL AREA..186

APPENDIX G. FOREST WOODY SPECIES DENSITY AND BASAL AREA.........189

APPENDIX H. DENSITY OF LOW MARSH DEAD WOODY VEGETATION COMPONENTS..194

APPENDIX I. DENSITY OF HIGH MARSH DEAD WOODY VEGETATION COMPONENTS...195

APPENDIX J. DENSITY OF TRANSITION DEAD WOODY VEGETATION COMPONENTS...196

APPENDIX K. DENSITY OF FOREST DEAD WOODY VEGETATION COMPONENTS...197

APPENDIX L. DEPTH (CM) OF ORGANIC RICH HORIZON BY SAMPLE PLOT...198

APPENDIX M. PERCENT SOIL ORGANIC MATTER BY ZONE..........................199

APPENDIX N. SOIL SALINITY (PPT) BY ZONE..200

APPENDIX O. ELEVATION (M) ABOVE MEAN SEA LEVEL FOR SAMPLE PLOTS...201

APPENDIX P. ZONE WIDTH (M) MEASURED IN THE FIELD............................202

APPENDIX Q. COASTAL FOREST RESISTANCE CLASSIFICATION WORKSHEETS..203

LIST OF FIGURES

1. Virginia portion of the southern Delmarva Peninsula..7

2. Geomorphic features of the southern Delmarva Peninsula and the three geographic regions defined for this study..11

3. Bell Neck Sand-Ridge complex of the central region and adjacent barrier islands..13

4. Geomorphic map of Virginia Coast Reserve showing approximate location of map transects...16

5. Landforms along the mainland fringe of the Virginia Coast Reserve....................19

6. Geomorphic map of Virginia Coast Reserve showing approximate location of sites sampled in the field...22

7. Field transects, sites, and sample plots..24

8. Width (m) of soil categories along each map transect..37

9. Width (m) of elevation intervals along each map transect...................................37

10. Number of streams by length class for three geographic regions..........................40

11. Number of streams in Strahler's stream order classes for the three geographic regions..40

12. Length (km) of upland and transition soils along valley perimeters in each geographic region..42

13. Length (km) of upland and transition soils along interfluve perimeters in each geographic region...42

14. Length (km) of upland and transition soils along the perimeter of islands 43

15. Length (km) of upland and transition soils along the perimeter of necks. 43

16. Method used to portray field data as two plots per zone I the high marsh and transition zones..46

17. Boxplots showing physical components of vegetation structure along a gradient from low marsh to forest....49

18. Boxplots showing dead vegetation components along a gradient from low marsh to forest....60

19. Boxplots showing depth of the organic rich horizon (cm) in each sample plot.....64

20. Boxplots showing the organic matter (%) of the soils (A) 0-10 cm and (B) subsurface (first 10 cm of the next deeper horizon), for each vegetation zone....65

21. Boxplots showing salinity (ppt) of the soil (A) 0-10 cm and (B) subsurface (first 10 cm of the next deeper horizon), for each vegetation zone....66

22. Scatter plots showing the relationship between F1's actual elevation and (A) the elevation difference between F1 and the average high marsh elevation, or L2 where the high marsh zone was absent, and (B) the slope between L2 and F1....76

23. The relationship between predicted and actual elevations of F1....77

24. Boxplots showing (A) actual elevation (m) above MSL and (B) actual and estimated elevation (m) above MSL, along a gradient from low marsh to forest..78

25. Ordination plot of forest sites using principal components analysis....86

26. Variables (A) elevation above MSL, (B) slope between F1 and L2, (C) elevation of forest above adjacent seaward zone, and (D) soil type, used to classify forest sites into three resistance groups: low (L), intermediate (I), and high (H)....87

27. Ordination plots of high marsh sites using principal components analysis....90

28. Variables (A) elevation of high marsh above low marsh, (B) slope of high marsh, (C) depth of organic rich zone from soil surface, (D) percent organic matter (0-10 cm), and (E) elevation of high marsh above MSL, used to classify high marsh sites into three resistance groups: low (L), intermediate (I), and high (H)....91

29. Boxplots showing distance from the nearest tidal source for the (A) forest, (B) transition, and (C) high marsh grouped by resistance groups: low (L), intermediate (I), and high (H)....94

30. Boxplots showing physical vegetation structure components for the three forest resistance groups: low (L), intermediate (I), and high (H)................95

31. Boxplots showing dead vegetation components for forest resistance groups: low (L), intermediate (I), and high (H)..99

32. Boxplots showing soil characteristics (A) salinity (0-10 cm), (B) depth of organic rich soil beneath ground surface, (C) percent organic matter (0-10 cm) for forest resistance groups: low (L), intermediate (I), and high (H)..100

33. Physical characteristics of transition sites grouped by their forest resistance groups: low (L), intermediate (I), and high (H)................................101

34. Boxplots showing vegetation structure components for transition sites grouped their forest resistance groups: low (L), intermediate (I), and high (H)..103

35. Dead vegetation components for transition sites grouped by their forest resistance groups: low (L), intermediate (I), and high (H)................................107

36. Boxplots showing soil characteristics: soil salinity (0-10 cm), depth of organic rich horizon from ground surface, and percent organic matter (0-10 cm) of transition sites grouped by their forest resistance groups: low (L), intermediate (I), and high (H)..108

37. Boxplots showing physical characteristics, not used in the classification, of marsh sites grouped by resistance: low (L), intermediate (I), and high (H).........109

38. Boxplots showing physical vegetation structure components for high marsh resistance groups: low (L), intermediate (I), and high (H)................................111

39. Boxplots showing dead vegetation components for high marsh resistance groups: low (L), intermediate (I), and high (H)..113

40. Map and field indicators for subgroups (A, B, C, D) of forest resistance groups (low, intermediate, high)..117

41. Number and percent of map sites within each forest resistance subgroup..........120

42. Number of sites within each forest resistance group by geographic region.........120

43. Pie charts showing percent of map sites in each forest resistance subgroup by geographic region....................122

44. Cross section of terrace plain through the three geographic regions....................124

45. Summary of changes that occur with each state change in response to rising sea level....................127

46. Examples of each forest resistance subgroup illustrated on soil survey maps and field cross sections....................143

LIST OF TABLES

1. Soil categories, series, symbols, drainage classes, and great groups for soils present along map transects....17

2. Vegetation zones occurring along the eastern mainland fringe of the Virginia Coast Reserve....23

3. Type of elevation measurements for each sample plot....28

4. Variables and scores used for forest state resistance classification....31

5. Variables and scores used for classification for high marsh state resistance....33

6. Area (hectares) of soil categories and elevation intervals for the three geographic regions....39

7. Length of coastline (boundary between forest and marsh) and percent of each forest soil category (transition = hydric, upland = nonhydric) along the coastline....44

8. Number of sample plots in each vegetation zone by site....48

9. Plant species present in the four vegetation zones....52

10. Relative percent ground cover (0-1 m) of species or other cover type in each vegetation zone....54

11. Importance values (IV) for woody species in the four vegetation zones for all field sites....56

12. Low marsh soil profile characteristics....62

13. High marsh soil profile characteristics....67

14. Transition soil profile characteristics....70

15. Forest soil profile characteristics....73

16. Elevation averages for plots and zones, and elevation differences within plots and between zones....80

17. Vegetation characteristics (A) physical structure, and (B) relative % ground cover (0-1 m) and species IVs for groundwater seeps......................... ...81

18. Elevation, zone width, and soil characteristics for ground water seeps.................83

19. Forest scores and ranks by resistance group: low (L), intermediate (I), and high (H)...85

20. High marsh scores and ranks by resistance group: low (L), intermediate (I), and high (H)..89

21. Relative percent ground cover (0-1 m) and woody species IVs for forest resistance groups: low (L), intermediate (I), and high (H)..................................97

22. Relative percent ground cover (0-1 m) and woody species IVs for transition sites grouped by their forest resistance group: low (L), intermediate (I), and high (H)...105

23. Relative percent ground cover (0-1 m) and woody species IVs for high marsh sites grouped by their resistance group: low (L), intermediate (I), and high (H)...112

24. Field sites listed with their respective zones and zone widths............................114

25. Map characteristics for each field site grouped by their subdivided forest resistance group...116

1. INTRODUCTION

Sea level has fluctuated throughout the course of geologic history, and currently it is rising. The rate at which sea level rises or falls has varied through time and is specific for a given location (Braatz and Aubrey 1987, Pirazzolia 1989). For this study, the context of a rising sea is used because it is the prevailing condition. The cause of sea level rise is a topic of current interest with several hypothesis under investigation. Some of these include glacio-eustatic changes, tectonic movements, changes in oceanic currents, and cyclic orbital forcing of oceanic and climatic changes (Milankovitch cycles) (Gornitz and Lebedeff 1987, Dott 1992). In addition, a recent effort has been undertaken to discern the effects that anthropogenic activities have on climate change and sea level rise. Some scientists believe that increasing atmospheric concentrations of carbon dioxide and other gases released by human activities are expected to warm the earth a few degrees Celsius in the next century by a mechanism known as the greenhouse effect (Titus 1987). They predict this warming will accelerate the rate of sea level rise.

Many studies have been conducted to determine the extent of global warming and its effects on sea level rise. The Intergovernmental Panel on Climate Change (IPCC 1995) reported that over the past century the mean global surface air temperature had increased between 0.3 and 0.6^{o} C. During this same 100 year period, sea level has risen between 10 and 25 cm. The researchers project this trend will likely continue in the future.

With the use of models, the IPCC developed a series of scenarios for prediction of global temperature and sea level changes by the year 2100. Under the extreme low scenario, they predicted a 1^{o} C increase in temperature and a 1 mm/year rise in sea level for a total of a 15 cm rise in sea level. Under the medium scenario, the IPCC predicted a 2^o C rise in air temperature by 2100, and a probable 50 cm rise in sea level. Under the extreme high scenario they predicted 3.5^o C increase in air temperature, and a rise in sea level equivalent to 9 - 10 mm/year for a total rise of 95 cm by the year 2100.

With the use of different models, other researchers have conducted similar studies to discern the extent of future sea level rise. Meier (1990) and Church et al. (1991) predict a 30 and 35 cm rise respectively, by the year 2050. Wigley and Raper (1992, 1993) estimate that sea level rise will be 4-5 times faster over the next century and foresee a 46 - 48 cm rise by 2100. Titus and Narrayanan (1995) predict a 34 cm rise in sea level by the year 2100. Despite the differences in the models employed, all of these recent best estimate predictions for future sea level rise fall within a range of 3 - 6 cm/decade (IPCC 1995).

A minor rise in sea level could cause a reduction in the world's coastal wetlands because most of them are within a few meters of current sea level (Titus 1991). A rise in sea level can disrupt wetlands in three major ways: salt water intrusion, flooding, and erosion. Depending on a wetland's landscape position, these forces may act to convert a wetland to an open body of water or tidal mud flat or change the vegetational composition of a wetland. The degree to which coastal wetlands will be affected by rising sea level depends on (1) the ability of the wetland to accrete either by mineral sediment deposition or autogenic peat accumulation, (2) the subsidence rate of the wetland, and (3) the distance available for marsh transgression over higher land.

The ability of a coastal wetland to accrete depends on the amount of mineral sediment input it receives and its ability to accumulate peat. Mineral sediment availability to a marsh depends on its tidal range, and size and erodability of its watershed. The coastal marshes of North Carolina's Pamlico and Albemarle Sounds are examples of areas with low tidal ranges (Moorehead and Brinson 1995, Young 1995). In contrast, mineral sediment deficits along the southern Delmarva Peninsula may be due to small watershed sizes (Oertel et al. 1992). Marshes deficient in both mineral and organic sediment have lower rates of accretion and are more prone to submergence. Many studies have been conducted to determine accretion rates and results indicate these rates are highly variable both temporally and spatially (Stevenson et al. 1986, Hackney and Cleary 1987, Cahoon and Lynch 1997). In some marshes peat accumulation and sediment deposition are sufficient to keep pace with the rising sea. For these marshes, net wetland acreage is either preserved or increased (Orson et al. 1985). However, in many marshes the rate of subsidence may negate any vertical growth due to accretion (Cahoon and Lynch 1997).

Deep subsidence may occur as a result of human induced activities such as oil and gas drilling, the dewatering of aquifers (Poland and Davis 1969), and shallow subsidence can occur from oxidation of peat due to increased drainage. Also, as sediment loading occurs, shallow compaction of the land causes a decrease in marsh elevation (Kaye and Barghoorn 1964, Stevenson et al. 1986). If accretion rates are unable to keep pace with subsidence rates or sea level rise, then the relative rate of marsh flooding increases (Nyman et al. 1993).

In response to rising sea level, coastal salt marshes naturally migrate over land (Fletcher et al. 1990, Oertel et al. 1992, Gardner et al 1992, Young 1995). During this process, tidal flat is converted to open water, intertidal mineral low marsh is converted to tidal flat or open water, organic high marsh is converted to mineral low marsh, and forested wetland or upland is converted to organic high marsh (Brinson et al. 1995). These conversions are termed state changes in contrast to successional changes because they are reliant upon external controls for their initiation (Brinson et al. 1995, Hayden et al. 1995). One would presume these state changes would conserve the area of wetland and a net decrease in forest would result. However, if the slope between the marsh and the upland is great or if impeding structures such as roads, dikes, or buildings have been constructed, then the migration of the marsh ceases (Kayan and Kraft 1979). As sea level continues to rise and open water moves landward, wetlands have no new surface area available, and consequently they diminish in size (Oertel and Woo 1994).

Evidence of the Holocene transgression has been documented for many areas. Some of these areas include Louisiana (Salinas et al. 1986), South Carolina (Gardner et al. 1992), North Carolina (Young 1995), Virginia (Hayden et al. 1991, Kastler and Wiberg 1995), New York (Clark 1986), and New Brunswick, Canada (Robichaud and Begin 1997). One specific example of transgression is demonstrated in a study conducted by Downs et al. (1994) on Bloodsworth Island, an island located in the Maryland portion of the Chesapeake Bay. The authors report a decline of 579 ha or 26 % of total land area for Bloodsworth Island between 1849 and 1992. Initially, the island's response to sea level rise was upland conversion to wetland; 79 % of island's 1849 upland area was lost by

1973, and hence there was no significant net change in wetlands. However, due to lack of available upland surface and rising rates in sea level, wetland loss is presently exceeding wetland gains.

For the purpose of coastal land management, it would be useful to develop an accurate methodology for predicting the future of a given landscape in response to rising sea level. To ensure this, in-depth field measurements would need to be taken at a very small scale (i.e. elevation measurements to the centimeter). Under most circumstances, this approach is unrealistic for large areas because of time and money constraints. A more practical approach would be to rely on maps to determine areas more susceptible to sea level rise. By employing a combination of soil survey maps, National Wetland Inventory maps, USGS topographic maps and aerial photographs in conjunction with field measurements, it may be possible to decipher many landscape features important in determining the fate of coastal land in response to rising sea level.

Several models that employ the use of map information have been developed to determine the extent of land class changes in response to sea level rise. Lee et al. (1991) developed a simulation model that predicted 40 % of the wetlands along the coast of northeastern Florida would be lost under a 1 m rise in sea level. The majority of that wetland loss was comprised of low marsh.

Kana et al. (1987a,b) developed a simple geometric model which they used to predict the reduction in coastal marshes under different scenarios of sea level rise by the year 2075 for two Atlantic coastal cities. For Charleston, SC under the low scenario of an 87 cm rise in sea level, there would be a net loss of about 59 % of the marsh and a 100 %

increase in tidal flats. The high scenario (159 cm) would result in an 80 % net reduction of wetlands. For Tuckerton, NJ under the low scenario of sea level rise, there would not be a major loss of total marsh acreage, although 90 % of the high marsh would be converted to low marsh. In the higher sea level rise scenario, 86 % of the marsh would be lost.

Another model developed by Park et al. (1991) is a spatial cell-based simulation model named SLAMM (Sea Level Affecting Marshes Model). This model was used on a much larger scale to predict the effects of a 1 m rise in sea level within the next century. They determined there would be a 26 to 82 % reduction in coastal wetlands within the conterminous United States.

Equipping ourselves with the knowledge of locations most likely to be intercepted by sea level rise could prove to be economically, socially, and environmentally advantageous. For the purpose of maintaining wetland ecosystems, it would be prudent to preserve areas most susceptible to sea level rise for marsh transgression. Furthermore, identifying these areas would steer potential developers and other property buyers from these high risk areas and avoid future losses.

The southern portion of the Delmarva Peninsula, which is bound on the east by the Atlantic Ocean and on the west by the Chesapeake Bay (Figure 1), is an area experiencing

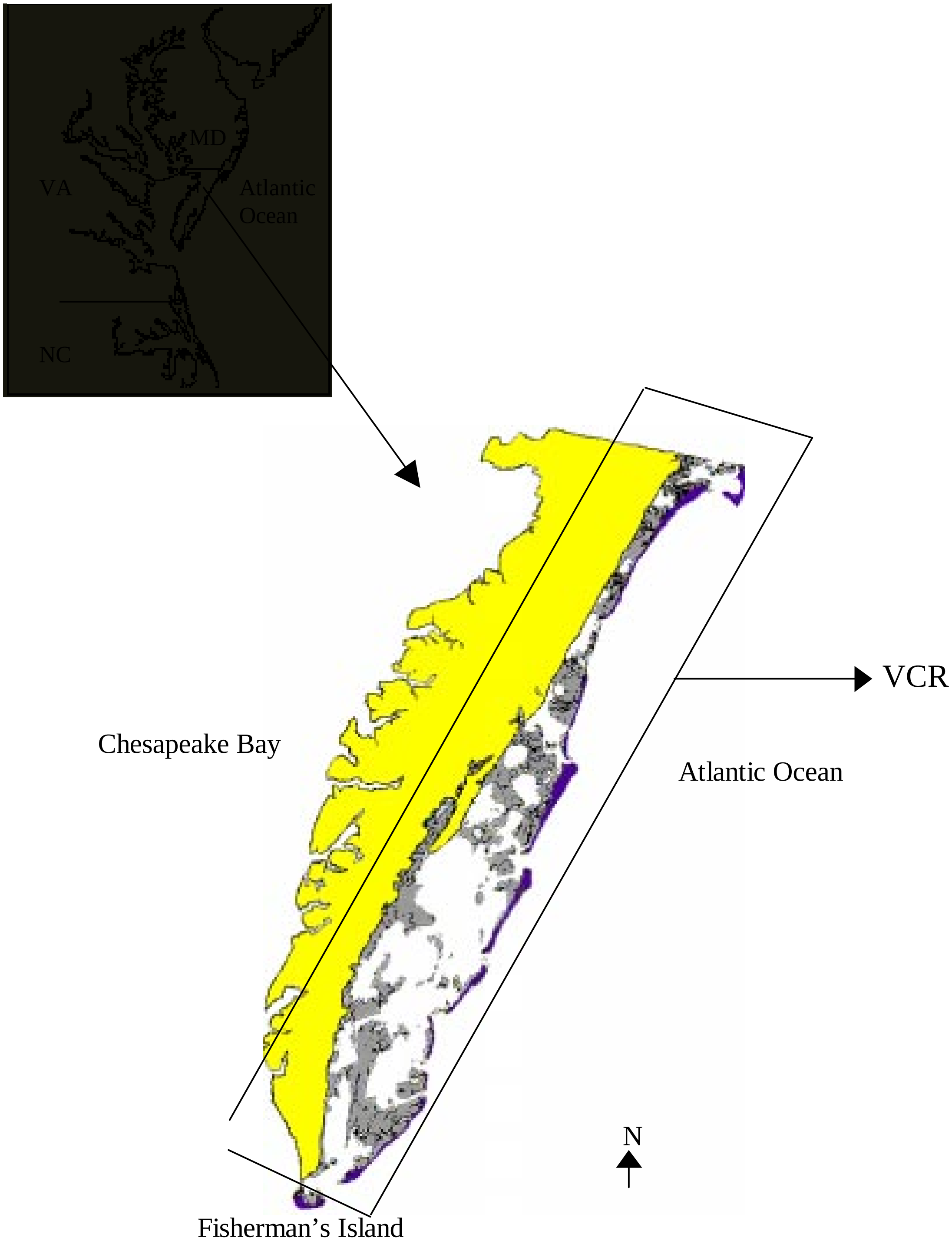


Figure 1. Virginia portion of the southern Delmarva Peninsula. Portions have been designated as a Long-Term Ecological Research Site, and are known as the Virginia Coast Reserve (VCR).

pronounced effects of the rising sea. This landscape is highly dynamic due to annual winds and storm surges and daily tides and waves. Since 1852, 16 % of the area's marshes have been lost to rising sea level (Hayden et al. 1991). Ecosystem changes that normally occur spatially at the continental biome level and temporally over glacial and interglacial periods, occur on decadal time scales on the southern Delmarva Peninsula (Hayden et al. 1995). Because this area is so dynamic, it is ideal for research on system state change and so has been designated as a Long Term Ecological Research Site by the National Science Foundation. Collectively, the area is known as the Virginia Coast Reserve (VCR).

The theme of the research conducted at the VCR is centered around how ecosystems are affected by changes in the vertical position of three free surfaces. These surfaces include the sea water, the fresh water table, and the land surface. Minor changes in the elevation or slope of these surfaces can result in major changes at the ecosystem/landscape level (Hayden et al. 1995). The central research hypothesis for the VCR has been divided into four subhypotheses which address these state changes at various levels and locations. At the largest scale, the Megasite hypothesis deals with changes in ecosystem states over a large geographic area (10's of meters to 10's of kilometers) and over a long time interval (decades to centuries). The remaining hypotheses cover smaller geographic areas and shorter time frames and are carried out in three locations. These areas include the barrier islands, the Hog Island Bay lagoons and marshes, and the mainland fringe marshes.

This study provides further insight for two of the research subhypotheses of the VCR. The purpose of this research project was to characterize the mainland fringe of the Megasite in terms of patterns where its coastal ecosystems may change with rising sea level, over a time scale of decades to a century. This study differs from those previously conducted in that it includes parameters at a fine enough level to make predictions at state change scales (10's of meters) as well as to be useful in making broad generalizations about the Megasite (10's of kilometers).

A five step process was used to accomplish this objective. First, the Megasite was characterized by its geomorphic features. Relevant geomorphic features include elevations at 1.5 m intervals, soil types, landform types, and stream sizes. Second, coastal ecosystem states along the Megasite were characterized by their geomorphic and ecological features. Geomorphic features at this scale include land surface elevations to the nearest cm, slope within and between states, and distance from a tidal source. Relevant ecological features include vegetation patterns and soil profiles. Third, ecosystem states were further classified into resistance groups based on their level of resistance to change into the next seaward state. Fourth, resistance groups were compared to determine if they were currently in different stages of state change. Finally, map and field indicators of various resistance groups were identified and used to produce a rapid assessment method for identification of forest resistance groups.

2. SITE DESCRIPTION

The study site is 99 km in length and extends from Cape Charles, VA north to Wallops Island, VA (Figure 1). In general, the southern portion of the Delmarva peninsula is comprised of a central upland bordered on the east and west by a series of terrace plains and lowlands (Mixon 1985) (Figure 2). The Metomkin, Mappsburg, and Kiptopeake scarps delineate the boundary between the central upland and the eastern terrace plains. These terrace plain surfaces are comprised of agricultural fields, upland and wetland forests, and salt marshes depending on the surface elevation, soil type, and proximity to a brackish water source. The central upland ranges from 10-19 m (35-60 ft) in elevation and the eastern terrace plains range from sea level to 8 m (26 ft) in elevation. To the east of the terrace plains lies a complex of salt marshes, tidal flats, lagoons, and barrier islands.

The study site ranges from 0.4 to 4.5 km in width, and extends from the 7.6 m (25 ft) contour line on the west, through the eastern terrace plains, and ends at the estuarine boundary on the east. Within the study area, there are three major terrace plains which include the Metomkin plain, Kiptopeke plain, and the Bell Neck Sand-Ridge complex (Mixon 1985). These plains extend for approximately 99 km from north to south with some overlap between them. The Metomkin plain lies the farthest north. It ranges in elevation from 7-8 m (23-26 ft) at the toe of the Metomkin scarp to 5 m (16 ft) or less at the western edge of the coastal lagoon and is approximately 41 km long. The Kiptopeke plain extends from Cape Charles north-northeast for about 16 km to where it is intersected by the Mappsburg scarp. This plain ranges in elevation from 8 m (25 ft) at the toe of the

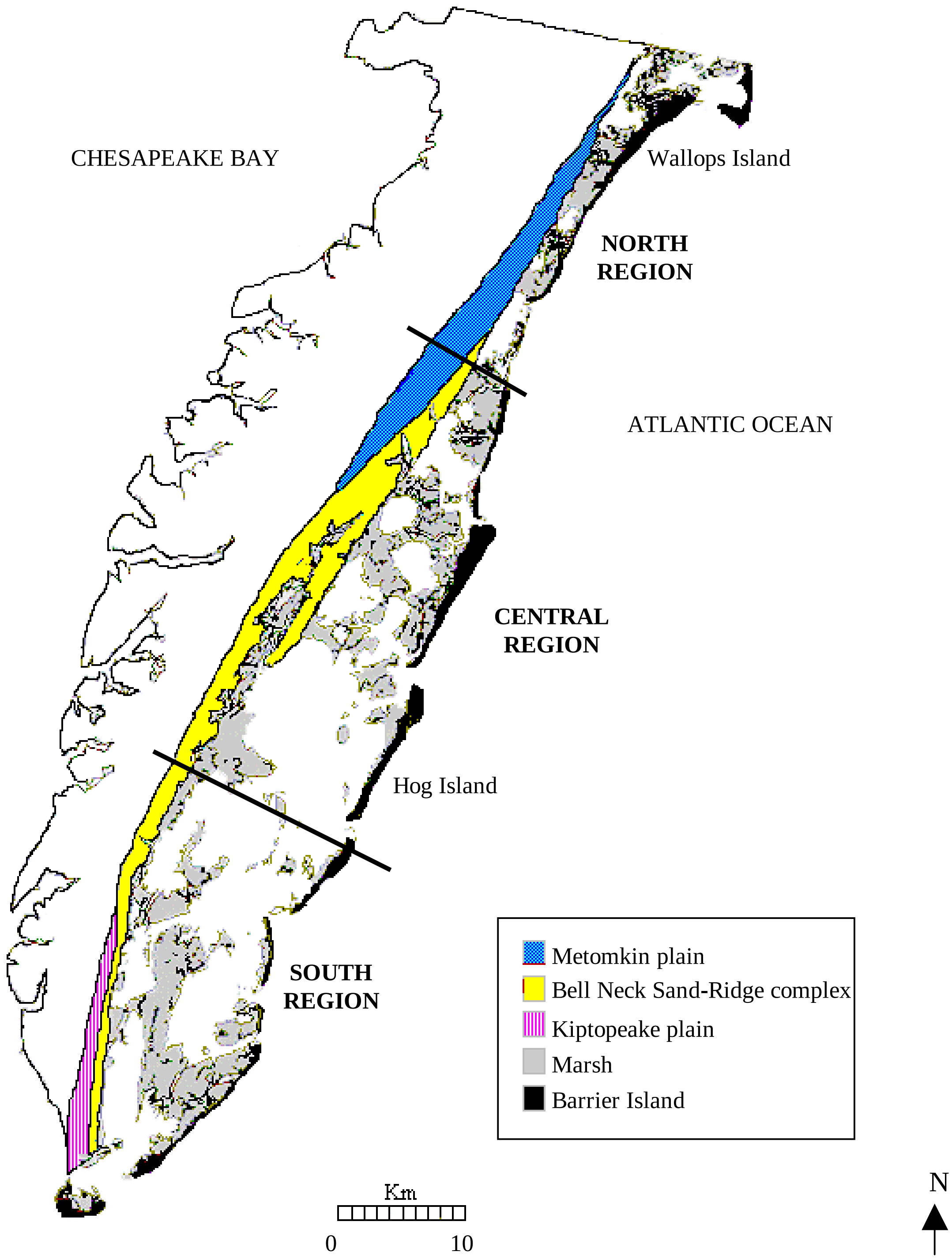


Figure 2. Geomorphic features of the southern Delmarva Peninsula and the three geographic regions defined for this study. The division of the three geographic regions corresponds to the presence of a series of relict regressive ridges in the central region.

Kiptopeke scarp to approximately 5 m (15 ft) at the eastern edge where it borders the Mappsburg scarp. The Bell Neck Sand-Ridge complex is a seaward-sloping coastal lowland that divides the Kiptopeke and Metomkin plains, extends for approximately 73 km, and ranges for 3-5 m (10-15 ft) at the toe of the Mappsburg scarp to sea level at the coastal lagoon (Figure 3). The middle and outer parts of this lowland comprise a series of alternating ridges and swales which have been interpreted as a regressive sequence of barriers and lagoons (Mixon 1985). The difference in elevation between ridge crest and adjacent crest is as much as 3 m (10 ft) in some places. Most of the swales have been flooded by the on-going Holocene transgression and presently are covered by salt marshes, whereas the ridges are in various stages of drowning.

Throughout this paper, the study area is divided into three geographic regions (south, central, north) (Figure 2). The division of these regions corresponds to the ridges of the Bell Neck Sand-Ridge complex (Figure 3), with exception of Mockhorn Island. Mockhorn Island is part of the ridge complex but is not within the confines of the study area. The south region encompasses all land south of the ridges the central region includes all of the ridges and the north region is comprised of study site surfaces north of the ridges. Ridges stand out on soil survey and topographic maps because they are often upland islands or necks surrounded by marsh. Initially, they were used as a source of division along the Megasite solely for exploratory purposes.

Terrace plain width differs between the three geographic regions. The south region has the narrowest average width (0.95 km) and a range from 0.45 km to 1.85 km.

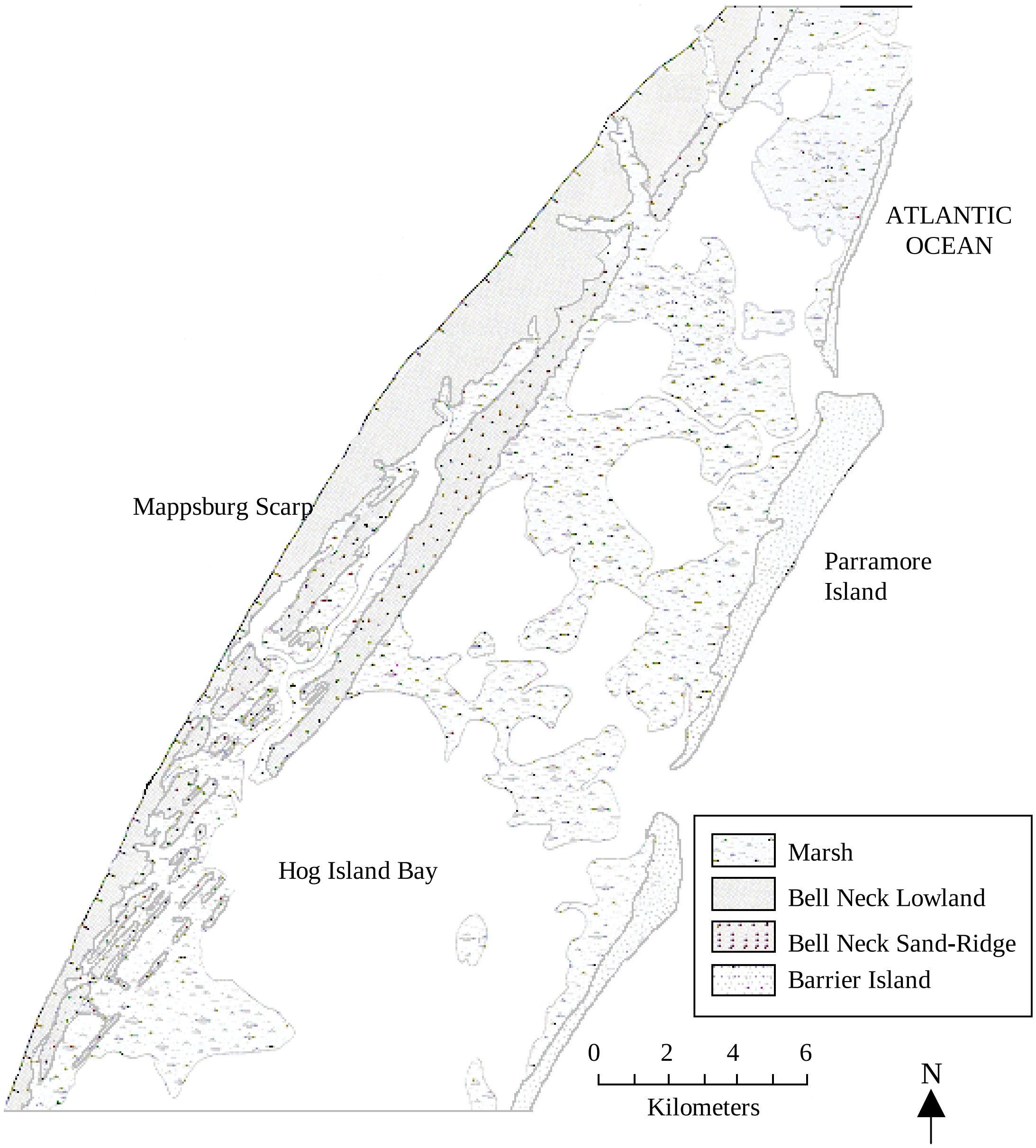


Figure 3. Bell Neck Sand-Ridge complex of the central region and adjacent barrier islands. Figure is modified from Figure 23 in Mixon (1985).

The central region has the widest terrace plain on average (3.2 km) and ranges in width from 0.74 km to 4.5 km. The north region has an average terrace plain width of 1.9 km and a range from 0.4 km to 3.3 km. The width of the marsh-tidal flat-lagoon complex varies along the length of the peninsula. This complex is widest within the central region and ranges between 4.5 - 13 km. The complex is narrowest in the north region where it ranges in width between 7.5 and 13 km. The width of the south region's marsh-tidal flat-lagoon complex ranges from 7.5 to 13 km.

3. METHODS

3.1 Megasite Characterization

Maps were used to characterize large scale geomorphic features of the Megasite. Transects were delimited, within the three geographic regions, on soil survey maps, National Wetland Inventory (NWI) maps, and United States Geological Survey (USGS) topographic maps. Map transects were oriented perpendicular to the coastline and scarps (Kiptopeake, Mappsburg, or Metomkin Scarp, whichever was farthest west) and extended from the 7.6 m (25 ft) contour line east to the estuarine boundary. For this study, the estuarine boundary demarks the location where the eastern most upland or marsh boundary of the study area meets open water. Map transects were placed every 3300 m along the length (north-south) of the study area (99 km) for a total of 30 transects (Figure 4).

Ten different soil series occurred along the map transects (USDA 1989 and 1994). These were grouped into three categories: marsh, transition, and upland soils. The marsh category includes the two hydric soil series present in marshes; transition soils include all hydric soils that do not exist in marshes; and the upland category includes all nonhydric soils (Table 1). For purposes of characterization, transect elevations above mean sea level (MSL) were divided into three intervals (0-1.5 m, 1.5-3.0 m, 3.0-7.6 m). Along each map transect, the proportion of the total transect width representing each soil series and elevation interval was measured. Distances or proportions measured along transects (east to west orientation) will be referred to as widths rather than lengths to avoid confusion with region or study site length (north to south orientation). In addition, the area (ha) of

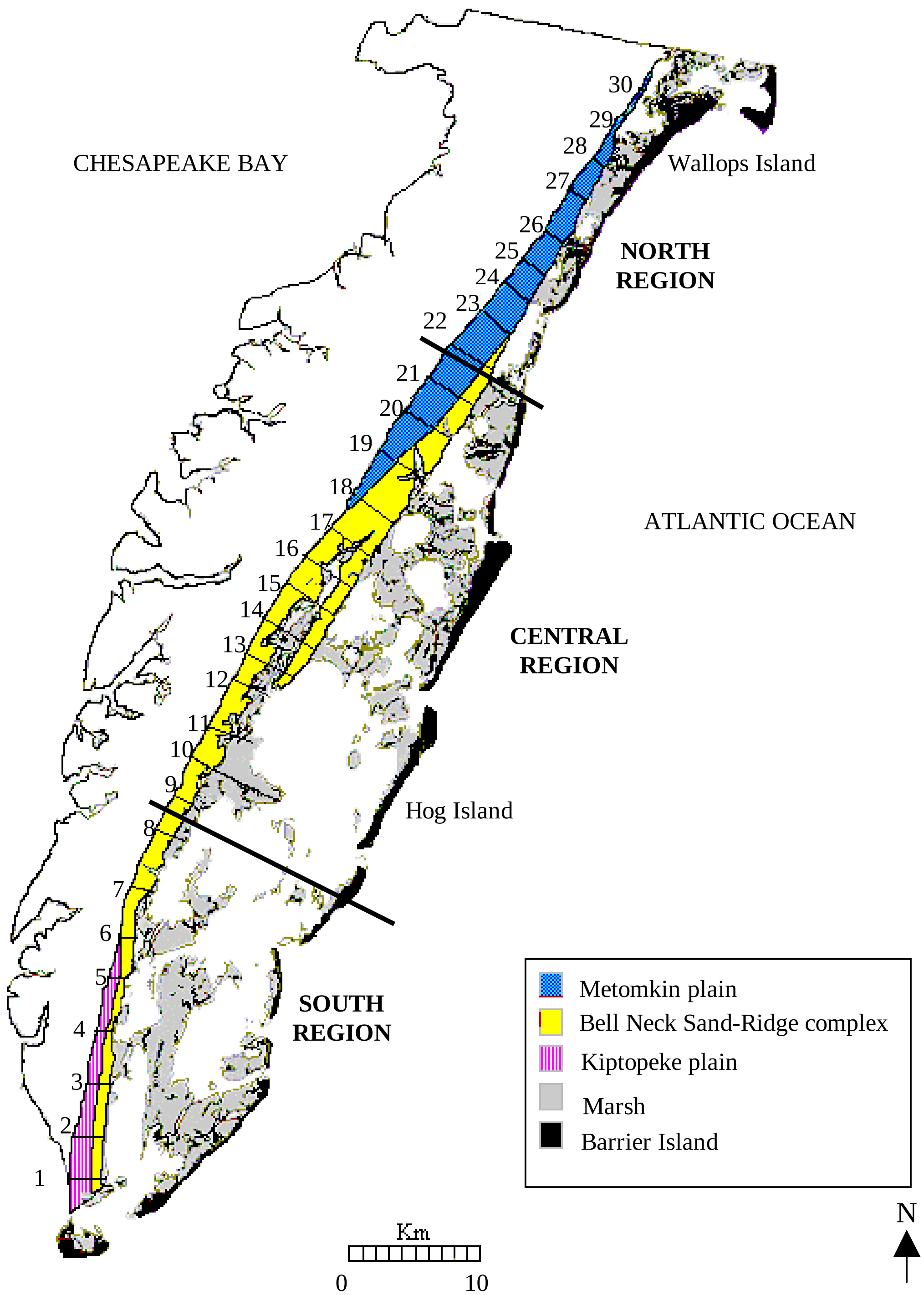


Figure 4. Geomorphic map of Virginia Coast Reserve showing approximate location of map transects. Map transects are labeled with their corresponding number.

Table 1. Soil categories, series, symbols, drainage classes, and great groups for soils present along map transects (USDA 1989, 1994). The three different soil symbols associated with the Bojac soil series represent different texture types (BoA = fine sandy loam, BkA = sandy loam, BhB = loamy sand).

Soil Category	**Soil Series**	**Soil Symbol**	**Drainage Class***	**Great Group**
Marsh	Chincoteague	ChA**	VPD	Typic Sulfaquents
	Magotha	MaA**	PD	Typic Natraqualfs
Transition	Nimmo	NmA**	PD	Typic Ochraquults
	Arapahoe	ArA, AhA**	VPD	Typic Humaquepts
	Dragston	DrA**	SPD	Aeric Ochraquults
	Polawana	PoA**	VPD	Cumulic Humaquepts
	Camocca	CaA**	PD	Typic Psammaquents
Upland	Munden	MuA	MWD	Aquic Hapludults
	Bojac	BoA, BkA, BhB	WD	Typic Hapludults
	Molena	MoD	SED	Psammentic Hapludults
	Udorthents	UpD	SPD - WD	Udorthents

***** VPD = very poorly drained, PD = poorly drained, SPD = somewhat poorly drained, MWD = moderately well drained, WD = well drained, SED = somewhat excessively drained

** = hydric soil

soil types and elevation intervals were calculated for each region. Area was determined by multiplying the length of each region by the average width of the transects it encompassed.

For each region, data was collected on the number of streams it contained and each stream's order and length. Stream attributes were only measured for the portion of the creek within the mainland, rather than following it until it entered the lagoon or ocean. Stream order was determined using Strahler's classification (Strahler 1957). Stream length is the sum of all branches entering into a creek.

I identified 4 major landform types (valley, interfluve, neck, island) (Figure 5) within the study area that were modified from a marsh classification described by Oertel and Woo (1994). I characterized the perimeter of each landform by its length and soil abundance by series. Perimeter length was traced along the boundary between the marsh and forest soils (upland or transition) bordering each landform perimeter (see Figure 5).

Valleys are landforms encompassing creeks currently being drowned by the Holocene transgression and as a result contain marsh soils. Because the main focus of this study concerns changes occurring on land surfaces rather than within the marsh, I use the term valley landform to describe the land surface fringing the drowned creek valley. Not all creeks were considered valleys; only land fringing creeks that contained marsh soils were classified as valley landform. Interfluves are the portion of the mainland between valley landforms. Valley and interfluve landforms occur at several different scales; so for clarity, those defined in this study were identified at scales detectable on soil survey maps (1:15,800).

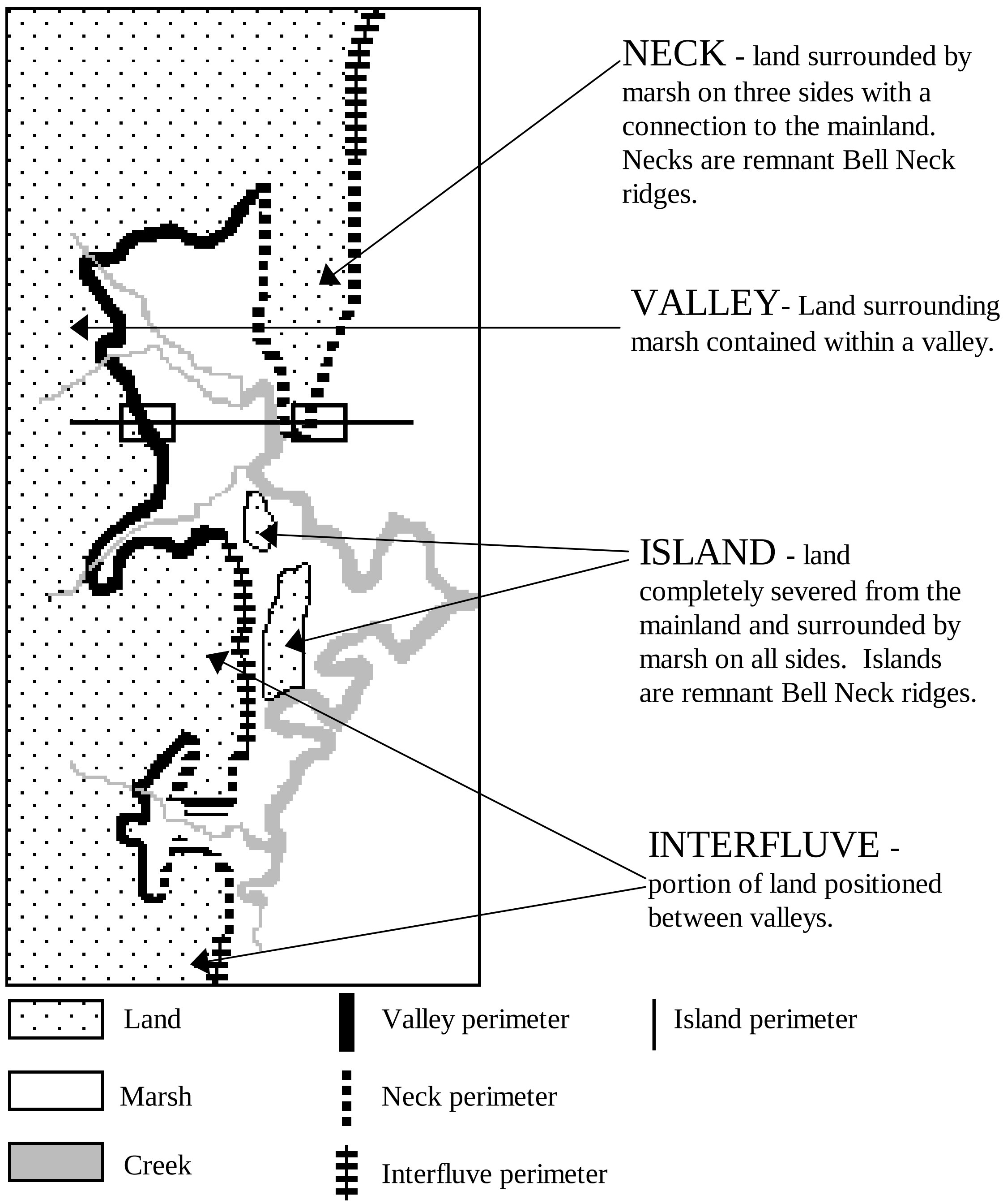


Figure 5. Landforms along the mainland fringe of the Virginia Coast Reserve. Four types of landforms were identified: valley, interfluve, neck, and island. The perimeter of each landform type is outlined differently so landforms can be distinguished. A hypothetical field transect is shown crossing two landforms with different sample sites represented by boxes. Landforms were identified on soil survey maps which are at a scale of 1:15,800.

Necks and islands are remnant Bell Neck ridges (Figure 3) that are in different stages of drowning. Ridges still attached to the mainland, but are predominately surrounded by marsh, are classified as necks. Necks are surrounded by marsh on three sides. Portions of necks still connected to the mainland were classified as interfluve. Necks often contribute a portion of their area to valley landforms. For locations where this occurs, neck surface is classified as neck rather than valley. Segments of land surrounded by marsh on three sides in the larger northern valley marshes (from Nicciwampus Creek north) were not classified as necks because they do not correspond to relict Bell Neck ridges. These are distinguishable from necks corresponding to Bell Neck ridges because they have a coast-normal orientation as opposed to the coast-parallel orientation of the Bell Neck ridges. Islands have been completely severed from the mainland and are surrounded by marsh on all sides.

Aerial photos from 1939 and 1941 were compared with photos from 1990 to determine if significant changes in the Megasite's zonation had occurred over the past 50 years in the vicinity of the transects. The earlier photos were at a scale of 1:20,000 and the more recent photos were at a scale of 1:660. This procedure's resolution was limited by the large scale of the earlier photos.

3.2 Ecosystem State Characterization

Field transects, a subset of the map transects, were used for ecosystem state characterization. The selection of transects for field sampling was based on accessibility and the degree of land alteration. Locations corresponding to map transects that were inaccessible or had been considerably altered by silviculture, construction, or impoundment activities were not used as field transects, or a location adjacent to them was chosen. For these reasons, several of the field transects differ from their corresponding map transect location. For some field transects, several positions along the transect were used to characterize ecosystem states; therefore, each location sampled along a field transect is referred to as site. A total of 20 sites from 16 field transects were sampled. In addition, three sites (BFF, BSN, 21B) not corresponding to map transects were sampled, for a total of 23 field sites (Figure 6). The additional sites were used because they were easily accessible and increased the field sample size. Several sites were chosen along a single field transect where various landforms were present. I ensured that all of the soil drainage classes and landforms were encompassed in the sites used for field sampling.

Sites were subdivided into 4 vegetation zones (forest, forest-marsh transition, high marsh, low marsh) which correspond to ecosystem states (Table 2). Each state has a unique suite of characteristics associated with it other than vegetational differences (Brinson et al. 1995). However, vegetation was used solely to delineate states in the field because plants were reliable indicators and rapidly identifiable. Therefore, I characterized each vegetation zone by its soil, vegetation, and elevational features. The sampling unit used for this characterization is termed a plot (Figure 7). Plots consisted of a 12 m diameter circle with the center point located on the field transect. I decreased the width of the plot diameter for vegetation zones with widths between 9 and 12 m. Two semicircles

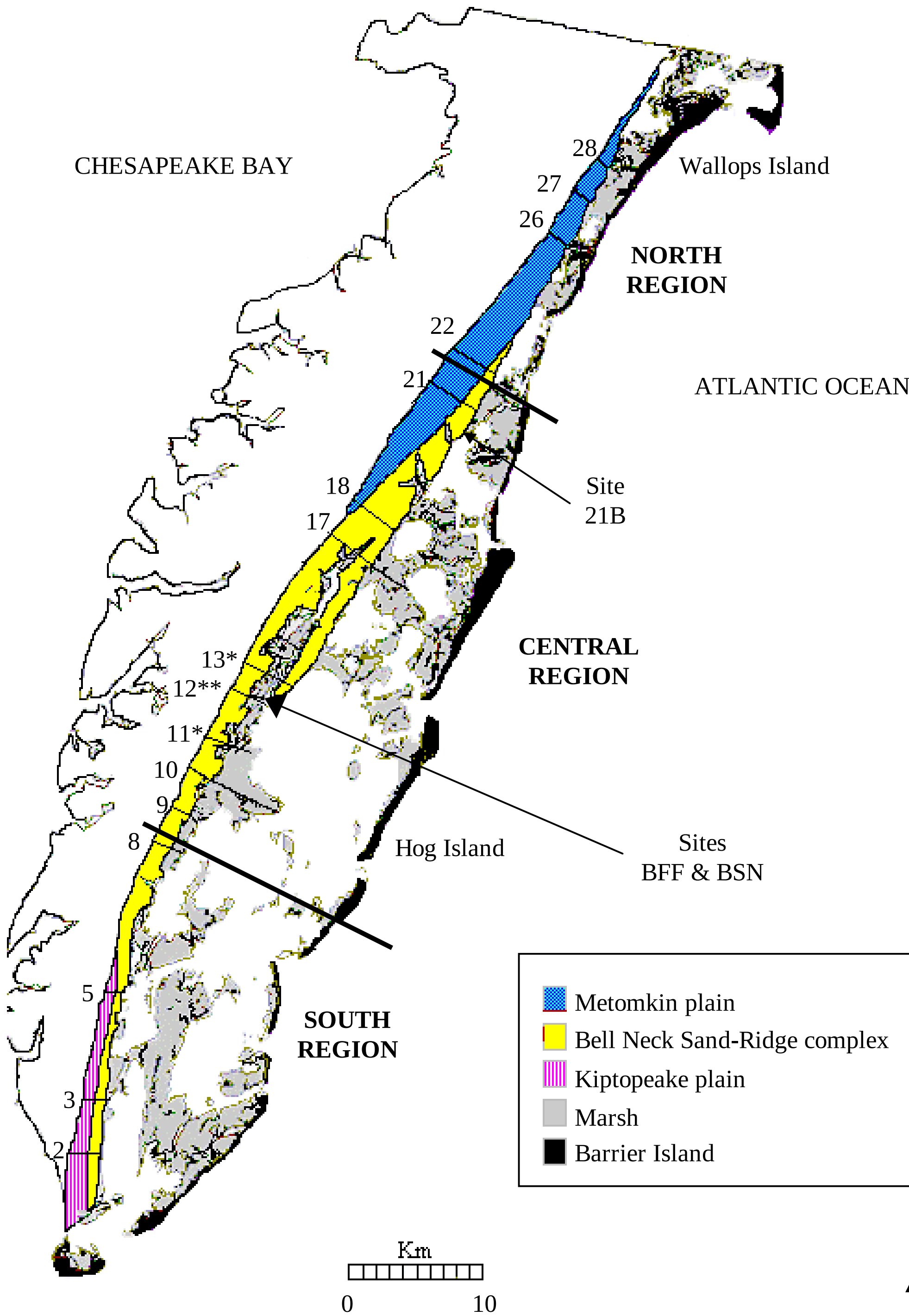


Figure 6. Geomorphic map of Virginia Coast Reserve showing approximate location of sites sampled in the field. Field transects with two sites are marked with an asterisk * and a field transect with three sites is marked with two asterisks **. Three sites (BFF, BSN, 21B) do not correspond to a map transect and are noted with an arrow.

Table 2. Vegetation zones occurring along the eastern mainland fringe of the Virginia Coast Reserve.

Vegetation Zone	Description
Forest	Zone dominated by trees and lacking marsh grasses.
Forest - Marsh Transition	Zone dominated by shrubs or small trees with the presence of marsh grasses.
High Marsh	Zone dominated by the marsh grasses *Spartina patens* or *Distichlis spicata*, or the rush *Juncus roemarianus*. Shrubs may be present but fall below 50% cover.
Low Marsh	Zone dominated by the marsh grass, *Spartina alterniflora*.

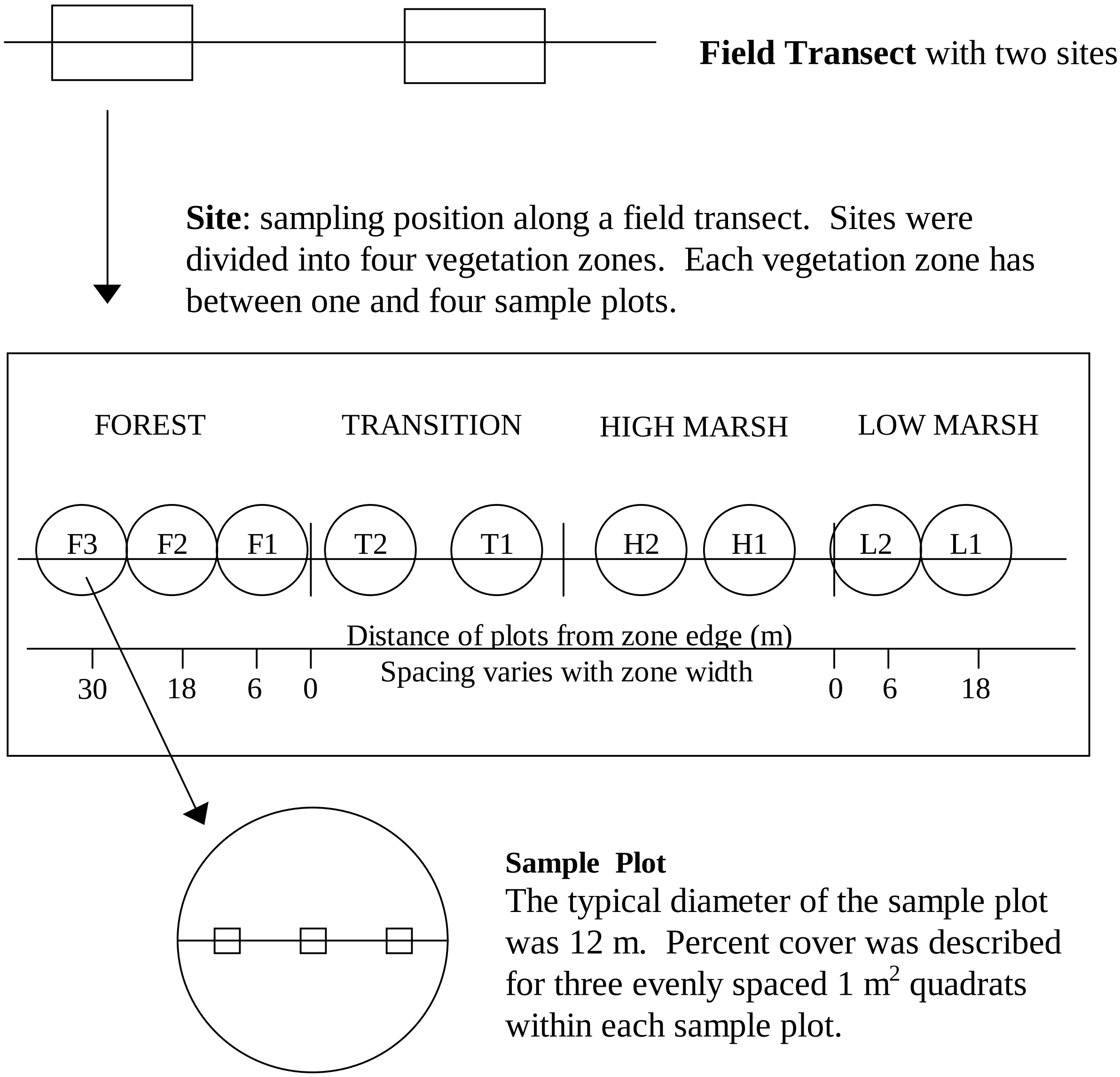


Figure 7. Field transects, sites, and sample plots. Sampling locations along field transects are referred to as sites. One to three sites were sampled along each field transect. Sites were divided into vegetation zones: forest, transition, high marsh, and low marsh. Within each vegetation zone, sample plots were used to collect data on vegetation, soil, and elevation characteristics. Three forest and two low marsh sample plots were placed in the same location at all sites for consistency. The number of plots sampled in the transition and high marsh increased with increasing zone width, with a maximum of four sample plots for a zone width of 202 m. These plots were evenly spaced along the transect within the zone. Each sample plot was numbered consecutively starting at the seaward side of the zone. Figure is not to scale.

were used as the sampling unit for zones with widths <9 m. The number of plots sampled in a given zone depended on the type of vegetation zone, zone width, and vegetation heterogeneity. For purposes of cross-site comparison, forest and low marsh sampling plots were consistently placed. Generally three plots were sampled in the forest and two in the low marsh with the center points located at 6, 18, and 30 m from the zone edge for the forest and 6 and 18 m from the zone edge for the low marsh. Fewer sample plots were used where zone width did not accommodate this configuration. The number of sampling plots for the high marsh and transition zones varied depending on zone width and were spaced evenly apart. Typically high marsh and transition zones had two sample plots but a few had as many as four or as few as one. Both forest and marsh zones were characterized similarly so that they were easily comparable during data analysis. Where applicable, six measurements were made for each sampling plot. First, the basal area (m^2/ha cross sectional area at 1.5 m above ground) for all live trees, by species, and dead trees >1m in height and $\geq$10 cm in diameter at 1 m in height were measured using calipers. Second, counts of live and dead trees and shrubs >1m in height, by species, were made. Third, using a 1 m^2 quadrat, percent cover was determined for two height intervals (0-1 m and 1-3 m). Percent cover estimates included the following classes: (1) vegetation by species, (2) dead trees (>1m tall), (3) dead shrubs, (4) natural stumps (<1m tall), (5) litter, (6) bare ground, (7) wrack, (8) potholes, (9) fiddler crab burrows, and (10) woody debris. Also, the percent cover of the canopy above 3 m was determined using a cylindrical tube for sighting. For all vertical positions, percent cover was estimated as the midpoint of one of the following eight cover classes: 0% (0%), 0 - 5% (2.5%), 5 - 25% (15%), 25 - 50%

(37.5%), 50% (50%), 50 - 75% (67.5%), 75 - 95% (85%), 95 - 100% (97.5%), and 100% (100%) (derived from Daubenmire 1968). Because cover classes were used rather than discrete values, cover percentages can exceed 100 %. Three sets of quadrat samples were taken within each circular plot. The quadrats were centered on the transect and were evenly spaced within the plot (Figure 7). Fourth, counts were made of all vines at 1.5 m in height. Fifth, the approximate age of the forest was determined by coring one of the older looking trees at 1.5 m in height. Finally, because the vegetation zones are not detectable on maps, their width was measured in the field.

Soil profile characteristics were evaluated at the midpoint of each vegetation zone. Soils were excavated using a soil auger and were described to a variable depth depending on the resistance of the soil, generally to a depth of at least 40 cm. Each soil horizon was described in terms of soil matrix color, mottle matrix color, mottle abundance, and texture. Soil colors were determined using the Munsell color chart and texture was determined by feel analysis (Thien, 1979). In addition, the first 10 cm of the soil and the first 10 cm of the next deeper horizon were brought back to the lab for determination of percent loss on ignition and salinity. Finally, the depth of the organic-rich horizon, when present, was measured at the midpoint of each sample plot.

Loss on ignition was determined for a sample of the soil surface (0-10 cm) and subsequent horizon (first 10 cm), for all sites, as an estimate of percent organic matter. First, the soil was homogenized by kneading it thoroughly in a ziplock bag. A portion of the homogenized soil was oven dried at 100 C until dry. Next, the dry mass of the soil was determined to the nearest 0.001g. The soil was then burned in a muffle furnace at

480 C for 3 h and then reweighed. The difference in mass was presumed to be the mass of the organic matter. This weight is reported as the percent of total soil mass. Triplicates for each soil sample were processed and their average is reported.

Soil salinity was determined for the soil surface and subsequent horizon, for all sites. A portion of the homogenized soil, described in the above section, was allowed to air dry for several days. A known mass of soil was mixed with a volume of distilled water twice the mass of the soil. This mixture was then shaken mechanically for 1 h. Next, the mixture was filtered through a glass fiber filter and then through a membrane filter with 0.80 μm pore size. For samples with clay, the mixture was filtered through a second membrane filter with pore size 0.45 μm. A YSI model 30 salinity, conductivity, and temperature meter was used to determine the salinity (ppt) of the filtrate. Of course, this is one of many ways to measure soil salinity.

The elevation of each sample plot was determined, at its center point, using a laser level. However, because there were rarely permanent benchmarks within the marshes, these elevations were not tied into mean sea level (MSL) and hence are not directly comparable among sites. A global positioning system (GPS) unit was used to determine the elevation above MSL for a portion of the study sites (Table 3). The GPS receiver used was a Trimble 4000 SE unit (L1 only) and the software used to process GPS data points was GPSurvey 3.20a. The elevations generated from the GPS are tied into MSL, according to the 1929 National Geodetic Survey, using a permanent bench mark (VCR1)

Table 3. Type of elevation measurements for each sample plot. Laser level elevation data was used to compare elevations within a site. GPS data was related to MSL and could be used to compare elevations between sites.

Site	**Laser Level Only**	**Laser Level & GPS**
2		X
3		X
5		X
8		X
9	X	
10		X
11	X	
11B		X
12JA		X
12JB		X
BFF		X
BSN		X
13		X
13H		X
17	X	
18	X	
21	X	
21B	X	
22	X	
26	X	
27	X	
28	X	
TOTAL	**10**	**13**

that has been established as a cignet global network tie. Detailed information concerning the establishment of the VCR1 benchmark can be found at internet address: www.vcrlter.virginia.edu/~crc7m/gps.html. Due to the high precision of the VCR1 benchmark, GPS elevations are accurate to the nearest centimeter and, therefore, can be used to compare sites. Two variables (slope and elevation) that were correlated with the forest elevation above MSL were used to develop a multiple regression equation. This equation was utilized to estimate the elevations above MSL for sites that were not near permanent bench marks.

3.3 Ecosystem State Classification

Forest and high marsh sites were each classified into three groups based on their level of resistance to change into the next seaward state. The transition was not classified because it is an intermediate stage between the forest and high marsh states. The low marsh was not classified because only the landward 24 m was characterized and this was not considered representative of the entire state. Variables used for the classification determine the extent to which brackish water is able to reach a site, and how long it will remain there. It is postulated that stressors introduced from stochastic storm events in addition to the slow drowning of the land drive state change (Brinson et al. 1995, Young 1995). Therefore, several variables were used to classify sites into resistance groups rather than zone elevation above MSL alone. These variables differ for the forest and high marsh.

Variables used to classify forest sites include elevation of forest above MSL, elevation of forest above adjacent seaward zone, slope between forest and low marsh, and forest soil drainage class. The two variables describing forest elevation determine the extent to which brackish water can reach the forest. Slope and soil drainage class determine the drainage potential of the forest, and subsequently the duration in which brackish water will persist in forest soils.

Three types of procedures were used to classify forest sites. First, each of the four variables were assigned a set of scores for all possible values (Table 4). Values were based on a 15 cm rise in sea level. This estimate corresponds to the IPCC's (1995) low estimate over the next 100 years, or their best estimate for the next 30 years. The three numerical variables (elevation above MSL and adjacent zone, slope) were given greater emphasis because preventing water from reaching a site provides more resistance to change than removing water once it is there, and slope probably influences drainage potential more than soil percolation rates (Harvey and Odum 1990). Scores were summed and sites with similar final scores were grouped together. Next, sites were ranked according to variable values and then the sum of ranks was compared. Finally, principal components analysis was used to produce an ordination plot depicting the similarity (in space) of the sites. The ordination was based on the slope and two elevational variables and did not include soil drainage type. All forest sites were used for this classification regardless of whether their vegetation and soil patterns were characterized.

Variables presumed to inhibit brackish water from reaching the high marsh on a regular basis include its elevation above MSL, and its elevation above the adjacent low

Table 4. Variables and scores used for forest state resistance classification.

Variable	Value & Score	Reasoning
Elevation above MSL	<1.25 m = 0 1.25 - 1.404 m = 1 >1.40 m = 2	Mean elevation of the transition zone is 1.10 m. Assuming a 0.15 m rise in sea level, forest elevations currently <1.25 m should be effectively lowered to the transition zone's position. The 0.30 m elevation difference above the current transition zone is used to suggest a much more resistant elevation.
Slope between forest and low marsh	< 0.01 = 0 0.01 - 0.02 = 1 >0.02 = 2	A 0.01 slope represents a significant change within a marsh considering the average elevation difference between the states is only ~ 0.2 m. Steeper slopes facilitate drainage and inhibit water flow upslope.
Elevation above adjacent zone	<0.15 m = 0 0.15 - 0.3 m = 1 >0.3 m = 2	Forests with a large elevational difference between them and their adjacent seaward zone should have greater protection from encroaching waters than those with only a small difference. All zones seaward of the forest are already under the influence of saline waters.
Soil drainage class	VPD, PD, SPD = 0 MWD, WD = 1	The duration of soil saturation and salt presence is longer for soils that have slower rates of drainage.

marsh. Variables that determine the drainage potential of the high marsh include its slope, thickness of organic rich stratum, and percent organic matter of the soil. The thickness of the organic matter also contributes to the elevation difference between the low and high marsh because as sea level rises, the organic matter oxidizes or erodes thus lowering its effective elevation (DeLaune et al. 1994).

Similar to the forest, three types of procedures were used to classify high marsh sites into resistance groups, assuming a 15 cm rise in sea level. First, scores were assigned to each variable for all possible values (Table 5). High marsh slope, thickness of organic rich stratum, and elevation difference between the low marsh and high marsh were thought to be the most critical factors in determining resistance to becoming low marsh and, therefore, were given higher weights than the other two variables. Because tidal range can vary locally, elevation above MSL was considered secondary to elevation above low marsh. Scores were summed for all sites, and sites with similar scores were grouped together. Next, sites were ranked according to variable values and then the sum of ranks was compared. Finally, principal components analysis was used to produce an ordination plot depicting the similarity of the sites.

3.4 Characterization and Comparison of Resistance Groups

The three forest and high marsh resistance groups (low (L), intermediate (I), high (H)) were characterized according to their tree density, basal area, and canopy cover; shrub density; dead shrub and tree densities; natural stump densities; species composition; soil characteristics; zone width; and distance from a tidal source. In addition, the

Table 5. Variables and scores used for classification of high marsh state resistance.

Variable	Value & Score	Reasoning
Slope of high marsh	< 0.01 = 0 >0.01 - 0.02 = 1 >0.02 = 2	A 0.01 slope represents a significant change within a marsh considering the average elevation difference between the states is only ~ 0.2 m. Steep slopes facilitate drainage and inhibit water flow upslope.
Elevation above low marsh	<0.15 m = 0 0.15 - 0.3 m = 1 >0.3 m = 2	A 0.15 m rise in sea level would lower the effective elevation of the high marsh to the low marsh's level (regular flooding) for marshes currently <0.15 m above their low marsh.
Depth of organic matter	>20 cm = 0 10-20 cm = 1 <20 cm = 2	Intervals are somewhat arbitrary.
Percent organic matter (OM)	> 20 % = 0 < 20 % = 1	Most soils with < 20 % OM lack a distinguishable organic horizon.
Elevation above MSL	< 0.87 m = 0 > 0.87 m = 1	Mean elevation of landward low marsh plot (L2) is 0.72 m. Assuming a 0.15 m rise in sea level, elevations currently < 0.87 m should be effectively lowered to L2's position.

transition zone was grouped according to its adjacent forest's group and was characterized by the features mentioned above. The Kruskal Wallis test was used to assess whether resistance groups were significantly different from each other for their variables characterized. The Kruskal Wallis test is a nonparameteric analysis of differences in means based on sample ranks. P values derived from this test were reported for variables characterized.

Sites not used in the classification due to missing forest zones (sites 10, 11B, 12JA) or incomplete elevation data (site 18) were placed into the resistance group they most closely resembled and were used to characterize sites. Forests with altered vegetation zones (i.e. by silvaculture, agriculture, or developmental practices) but complete elevation and slope data were used in the classification but not for the soil and vegetation characterizations. Sites used this way include 17, 21B, 27, 28.

3.5 Identification of Map and Field Indicators of Resistance Groups

Forest resistance groups were characterized by their landforms, transition zone and high marsh zone width, width of hydric soils, width of Magotha soil series, and width of elevations between 1.5 - 3.0 m along map transects. Results were used to subdivide the three forest resistance groups into map and field identifiable groups. I was unable to identify any map indicators of high marsh resistance groups. Finally, map indicators were used to characterize the resistance of all forests adjacent to marshes that occurred along the 30 map transects, seven nonmap field sites, and an additional 30 map transects. The additional map transects were placed midway between the original 30 transects.

Additional transects were added to insure indicators were applicable to sites that I had not used in my study. A total of 149 forest sites were used in this characterization.

4. RESULTS

4.1 Megasite Characterization

Marsh soils tended to occur below 1.5 m, transitions soils were most dominant between 1.5-4.5 m, and upland soils were prevalent at all elevations above 1.5 m (Table 1). Widths along map transects of the three soil categories (marsh, transition, upland) and elevation intervals varied by geographic region (Figures 8 and 9). Map transects in the south region appeared to fall into two subgroups with 1-3 distinct from 5-8. Map transects 1-3 consisted of at least 200 m of transition soils whereas map transects 4-8 all had <80 m of transition soils. Both subgroups, however, were generally dominated by upland soils with an average of 56 % upland. On average, map transects in the south region had little marsh or elevations below 1.5 m.

Map transects in the central region were generally composed of marsh and transition soils, and elevations <3.0 m (Figures 8 and 9). The superabundance of transition soils in map transects 17-21 corresponds to a trend of greater watershed size in this region's northern end (map transects 9-16). The two transects at each end of the central region (9 in the south and 21 in the north) show similar features to regions adjacent to them indicating their geographic affinity.

Map transects in the north region were similar to those of the south region in that they had little marsh and transition soils, and elevations <3 m (Figures 8 and 9). Map transects 27 - 30 are shorter than 22-26 indicating a decrease in eastern terrace plain width in the northern portion of the north region. Upland soils and elevations >3.0 m decline in abundance as the terrace plain diminishes in width. In contrast, the abundance

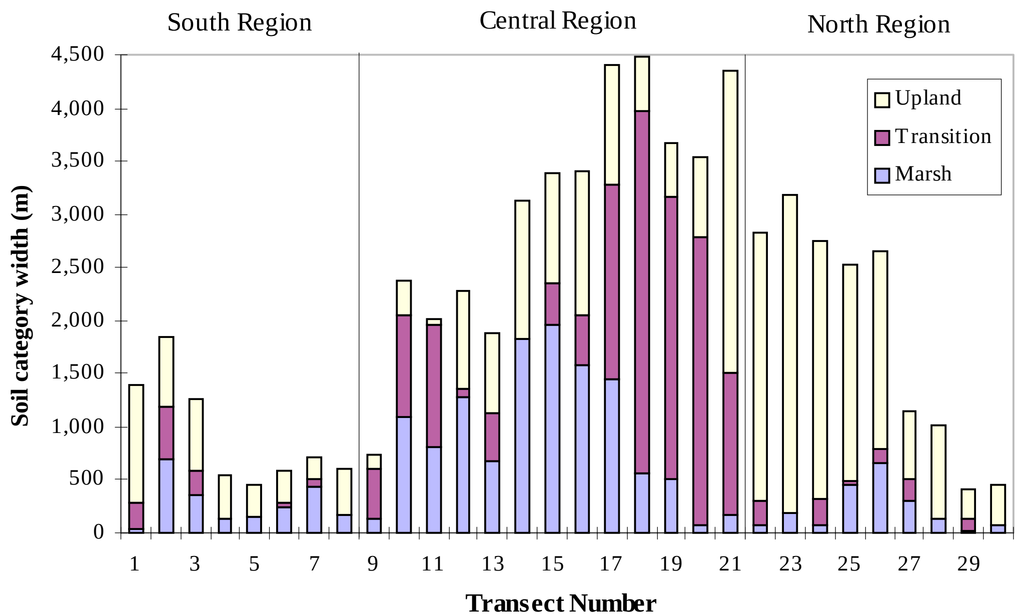


Figure 8. Width (m) of soil categories along each map transect.

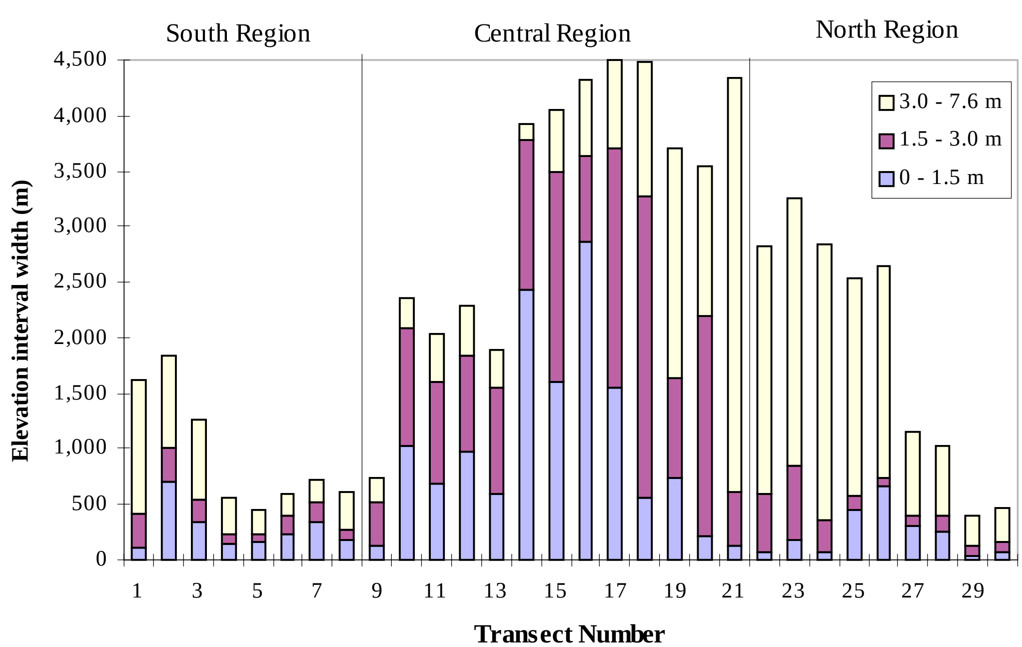


Figure 9. Width (m) of elevation intervals along each map transect.

of marsh and transition soils and elevations <3 m does not decline with diminishing terrace plain width.

In terms of area (length of region x average width of map transects in region), the north and south regions have little marsh and transitions soils, and elevations <3m (Table 6). However, the north region has almost three times more upland soils and elevations >3-7.6 m than the south region. The central region has more that five times the area of marsh soils and elevations <1.5 m compared with the north and south regions, and at least 11 times the area of transition soils and elevations 1.5-3 m compared with the north and south regions (Table 6).

Most of the watersheds along the southern Delmarva Peninsula are small, but watershed sizes generally become progressively larger from the northern end of the central region northward. The largest watershed of the study area is the Machipongo River which occurs in the central region. The Machipongo River watershed is comprised of eight tributaries that feed into Parting Creek which in turn feeds into the lower portion of the Machipongo River, and eight tributaries that feed into the upper portion of the Machipongo River.

Six stream length classes have been designated to illustrate differences in watershed size among regions. Most streams occurring in the central and north regions, and all streams occurring in the south region, are relatively short in length (Figure 10). Of the three regions, the north region has the most longer streams. Furthermore, according to Strahler's stream order, the north region has the largest number of higher stream orders

Table 6. Area (hectares) of soil categories and elevation intervals for the three geographic regions. Area was calculated by multiplying the length (north - south) covered by each region by the average width (east - west) of the map transects it encompassed.

	Area (ha)		
	South Region	Central Region	North Region
Soil Category			
Marsh	779	3,998	615
Transition	389	5,254	299
Upland	1,427	3,830	4,376
Elevation Interval			
0 - 1.5 m	776	4,454	658
1.5 - 3.0 m	491	5,420	654
3. 0 - 7.6 m	1,413	4,038	4,033

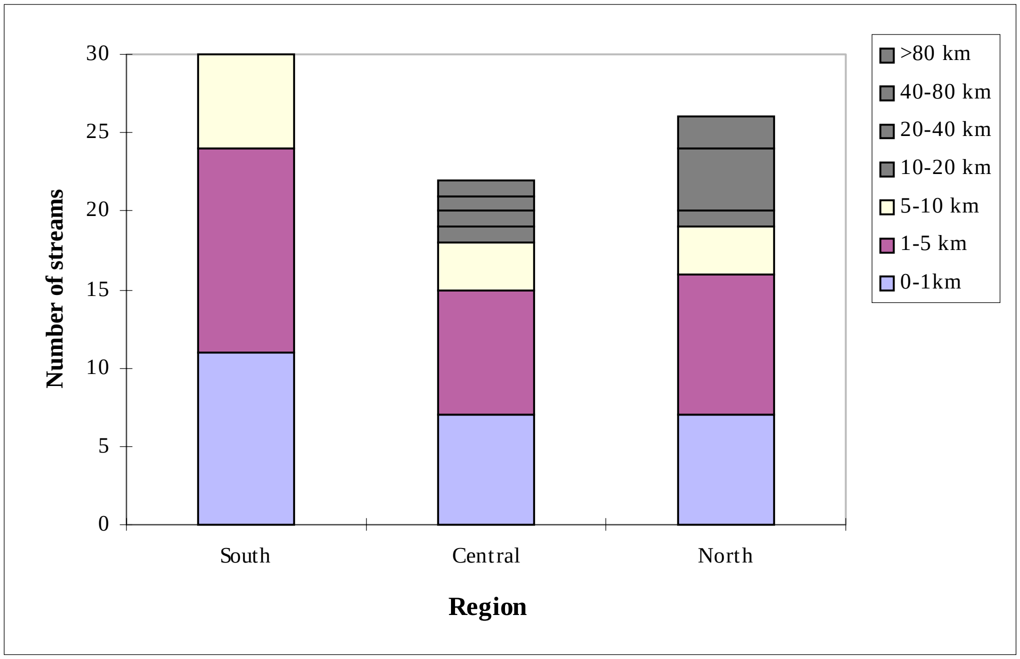


Figure 10. Number of streams by length class for the three geographic regions.

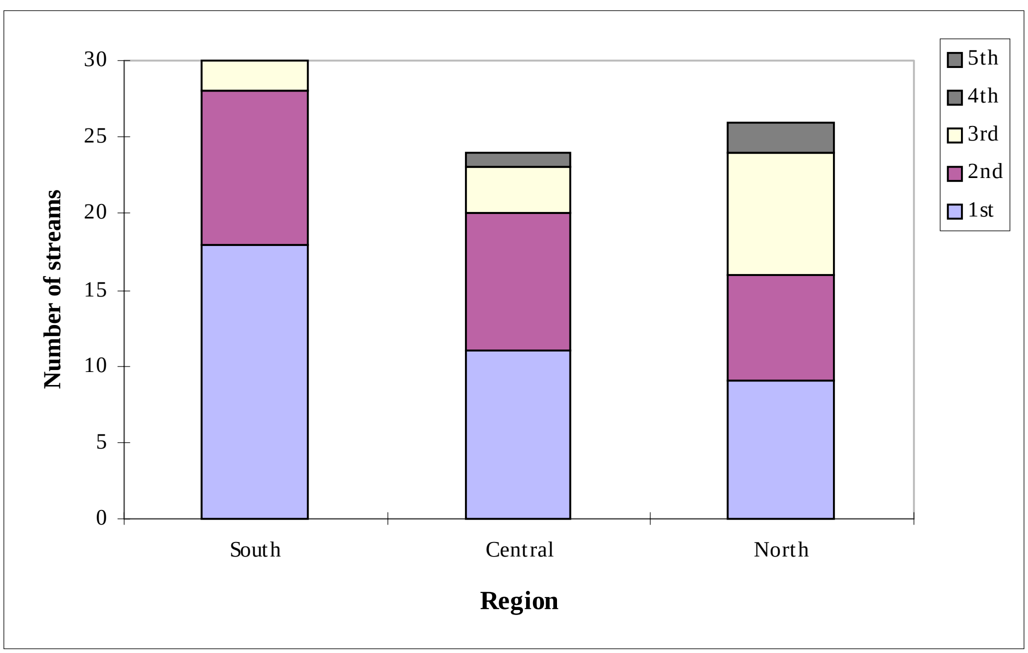


Figure 11. Number of streams in Strahler's stream order classes for the three geographic regions.

followed by the central region and then the south region (Figure 11). The Machipongo River is the only 5th order stream in the study area.

Fifty percent of the creeks in the south region, 67 % of the creeks in the central region, and 62 % of the creeks in the north region contained marsh soils, and therefore were classified as valleys. The central region had the most valley landform length, followed by the north region and then the south region (Figure 12). Less than 15 % of the valley landform perimeters in the north and south regions were adjacent to forest transition soils (hydric soils). In contrast, 37 % (~ 40 km) of the valley perimeter in the central region was adjacent to transition forest soils. Most interfluve perimeters occurring in the south region consisted of transition forest soils whereas those occurring in the central and north regions were predominately comprised of upland forest soils (Figure 13). Although the central region had the most land area, it had the least perimeter length of interfluve landform. All island and neck landforms occurred in the central region; and for both landforms, upland soils made up the largest proportion of forest soils along the land/marsh perimeter (Figures 14 and 15).

In summary, the central region had the longest coastline defined as the boundary between marsh and forest (length = 262 km), the south region had the shortest coastline length (45 km), and the north region coastline was of intermediate length (94 km) (Table 7). Fifty percent of the coastline in the south region, 32 % in the central region, and 16 % in the north region were bounded by forest transition soils (Table 7).

Recent (1990) aerial photos did not reveal any detectable differences in vegetation zonation or creek position along the 30 map transects from the 1938 and 1941 photos.

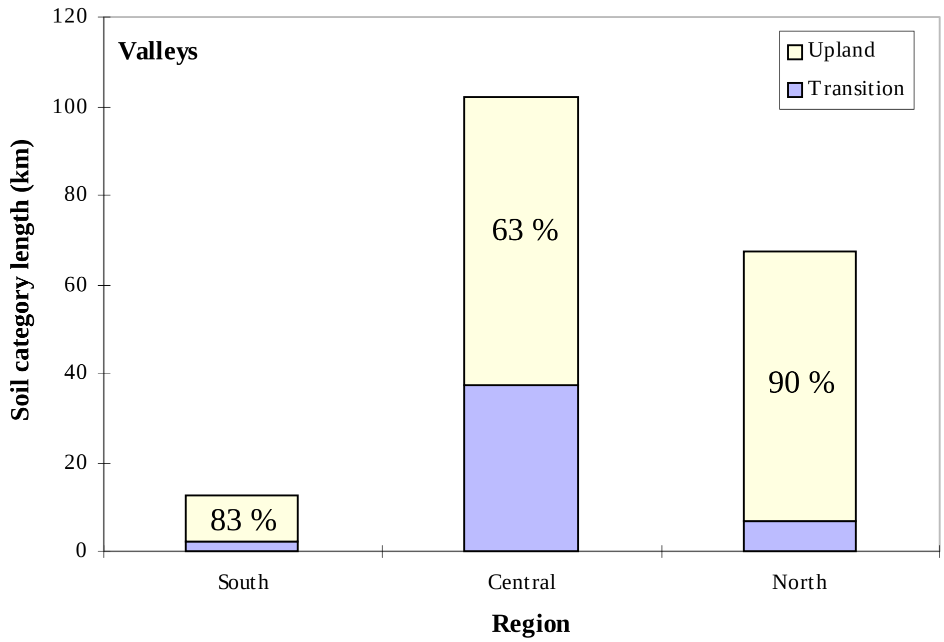


Figure 12. Length (km) of upland and transition soils along valley perimeters in each geographic region.

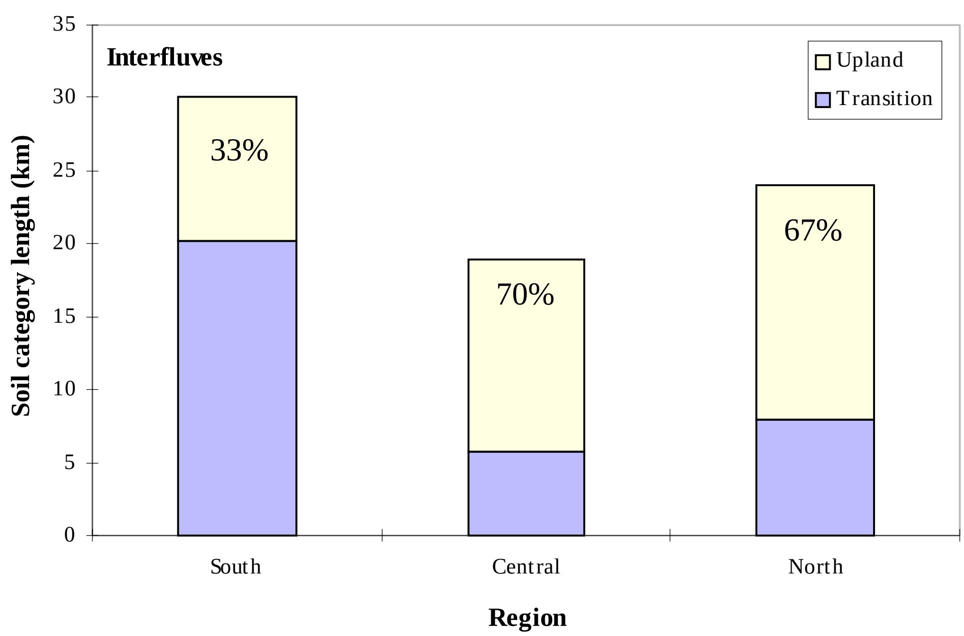


Figure 13. Length (km) of upland and transition soils along interfluve perimeters in each geographic region.

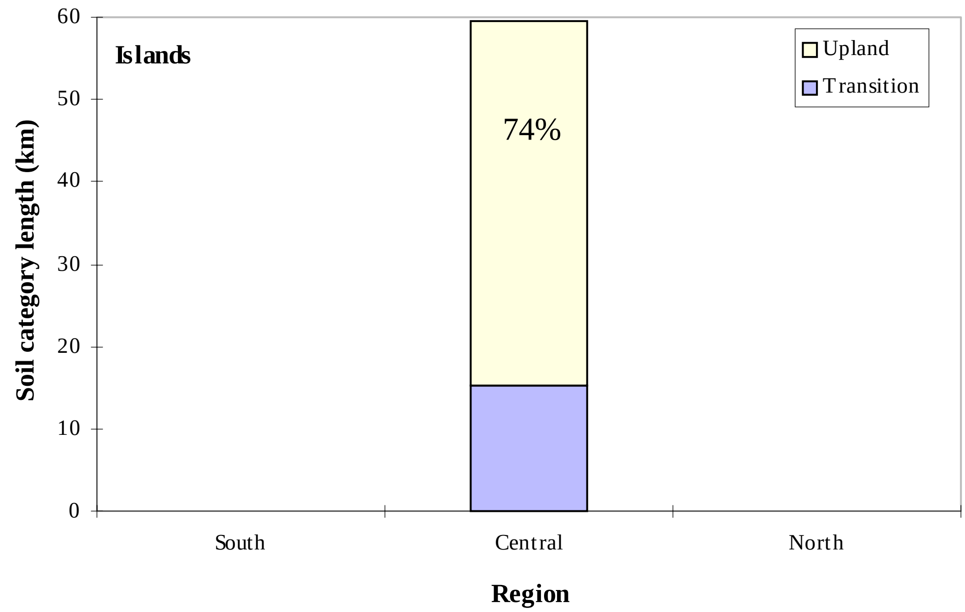


Figure 14. Length (km) of upland and transition soils along the perimeter of islands. Islands correspond to relict Bell Neck ridges that occur in the central region.

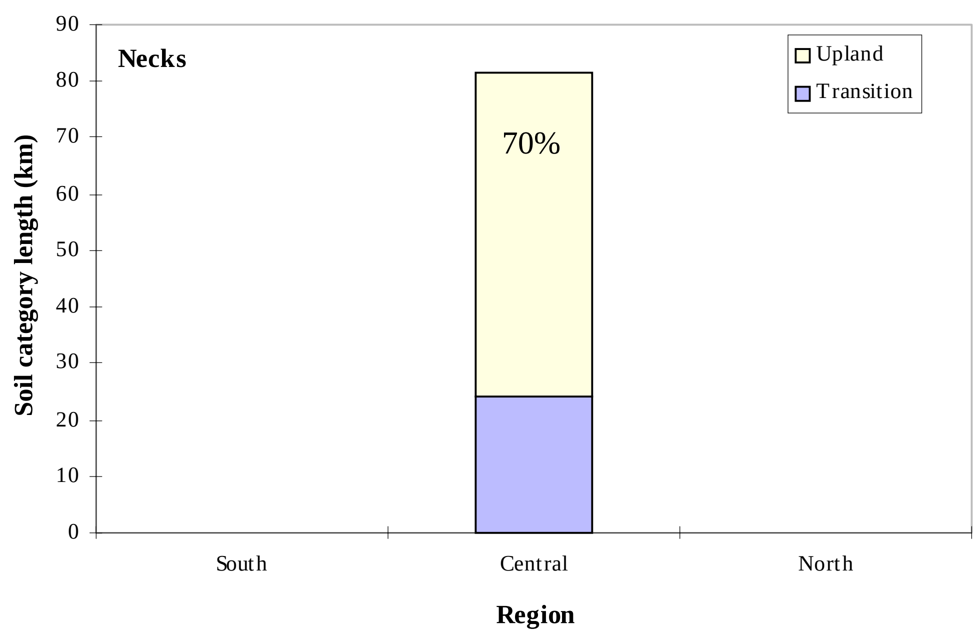


Figure 15. Length (km) of upland and transition soils along the perimeter of necks. Necks correspond to relict Bell Neck ridges that occur in the central region.

Table 7. Length of coastline (boundary between forest and marsh) and percent of each forest soil category (transition = hydric, upland = nonhydric) along the coastline.

Region	Coastline length (km)	Transition soils (%)	Upland soils (%)
South	45	50	45
Central	263	32	69
North	94	16	82

Creek positions and vegetation zone boundaries appeared to be in the same position for both years compared. However, any changes involving only a few meters would not be detectable given the large scale (1:20,000) of the older photos.

4.2 Ecosystem State Characterization

Not all vegetation zones were present at all sites. Four sites (9, 11B, JB, BFF) lacked low marsh, six sites (5, 8, 10, 11, 12T, 21) lacked high marsh, three sites (5, 17, 27) lacked transition zone, and nine sites (10, 11B, JA, 13H, 17,18, 21B, 27, 28) lacked forest zone. Most of the missing forest zones were due to the conversion of forest with agriculture fields. In addition, two of the sites (5, 27) had groundwater seeps, which did not fit the criteria for any of the four vegetation zones defined for this study.

Due to variation in the widths of vegetation zones, not all zones had the same number of sample plots within them. In order to show within-zone variation along a gradient from sea to land and to maintain consistency for comparing sites, data from the high marsh and transition zones are represented by two plots. These plots are reported as H1, H2, T1, and T2, with both number 1 plots representing zone data closer to the sea and number 2 plots representing zone data closer to the land (see Figure 16). In order to portray data as two plots per zone for zones where more or less than two plots were field sampled, data were either averaged or represented twice. More specifically, zones where there were four plots sampled, plots 1 and 2 were averaged to represent T1 or H1 and plots 3 and 4 were averaged to represent T2 or H2. For zones where there were three

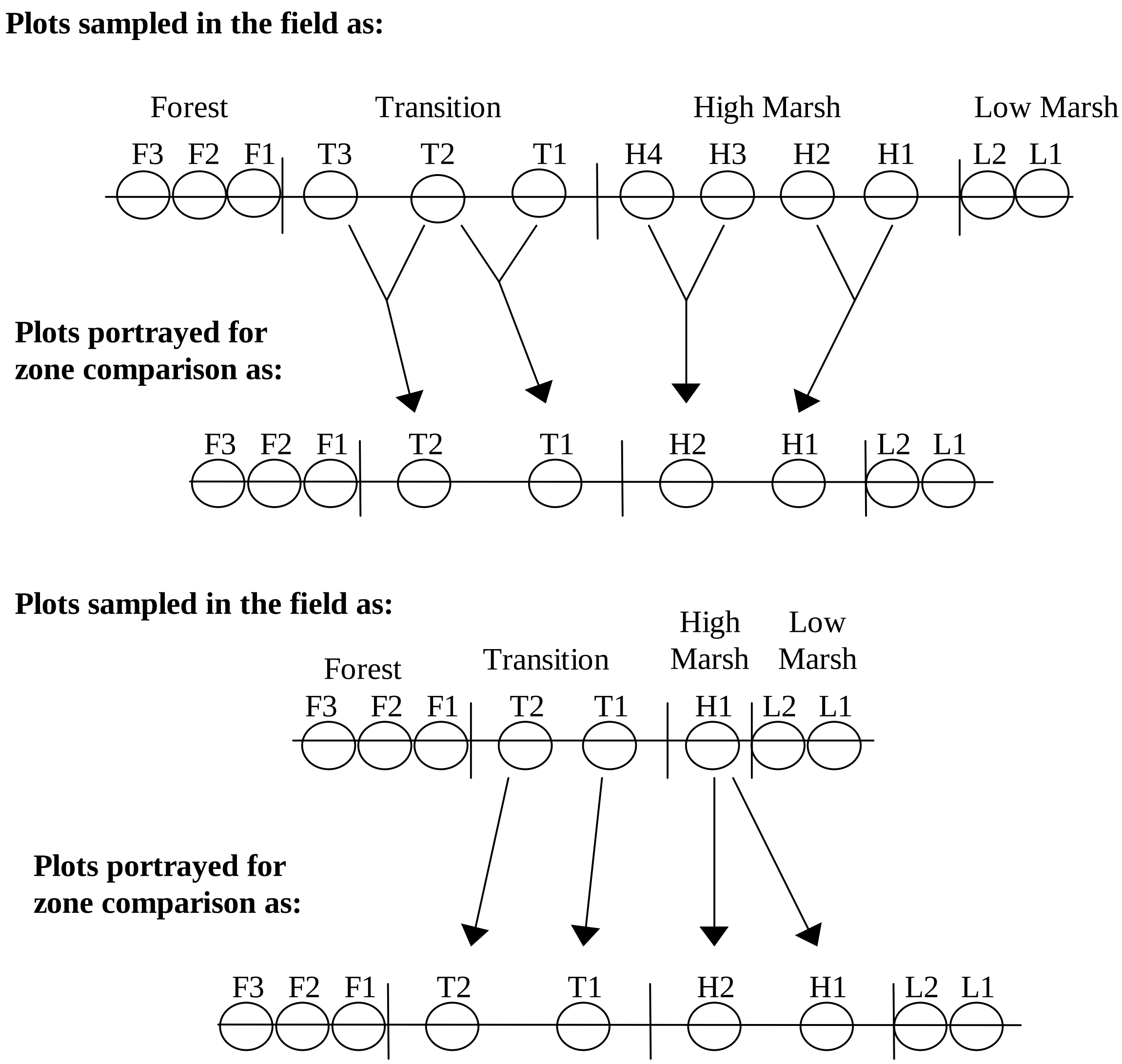


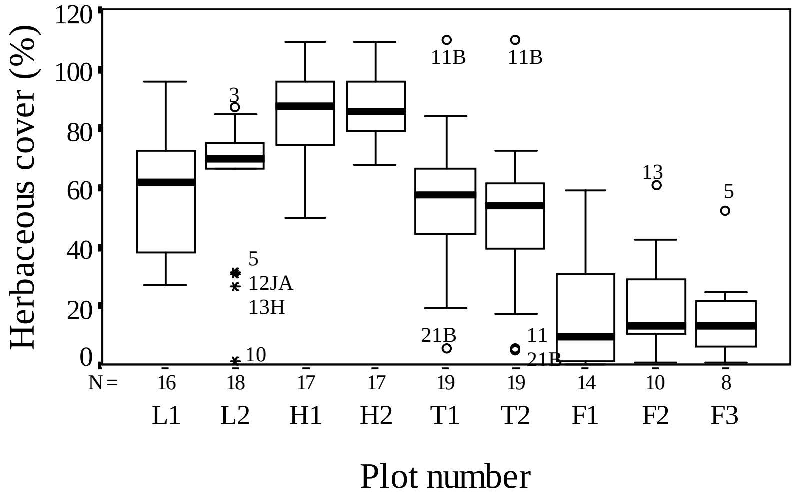
Figure 16. Method used to portray field data as two plots per zone in the high marsh and transition zone. For high marsh and transition zones with four sample plots, plots 1 and 2 were averaged and plots 3 and 4 were averaged. For zones with three sample plots, plots 1 and 2 were averaged, and plots 2 and 3 were averaged. For zones with two sample plots, both plots were represented individually. For zones with only one plot, that single plot was represented twice. All plots sampled in the field for the forest and low marsh zones are represented individually because they were consistently placed for all sites and therefore are directly comparable.

plots sampled, the middle plot was averaged with both the 1st and 3rd plots. Zones that were so narrow that only one plot was sampled showed no within-zone variation at a scale in which I was interested. However, this single plot was represented as both the number 1 and 2 plots in order to show that its characteristics occurred next to the landward and seaward side of that zone. All plots are represented individually for the low marsh and forest zones because these plots were consistently placed in the field and therefore are directly comparable. Table 8 summarizes the total number of plots sampled for each vegetation zone.

Low marsh vegetation consisted entirely of herbaceous plants, and because it had no shrubs or trees, it lacked measurements for tree basal area and canopy cover (Figure 17). There was a broad range in terms of vegetated ground coverage in the low marsh, but in general, vegetative cover increased inland towards the high marsh. The mean cover in L1 plots was 56 % and the mean cover in L2 plots was 64 %. The high marsh also was dominated by herbaceous cover, had a few shrubs, and no trees. The high marsh had the highest percent of herbaceous cover among the four zones and had a lower range in cover than the low marsh. The range in herbaceous cover decreased and the number of shrubs slightly increased in the landward plot (H2) of the high marsh. The transition zone was moderately vegetated by herbaceous plants, had a large number of shrubs, very few trees, and consequently low basal area and canopy cover. Herbaceous cover in the transition and forest zones includes vines <1 m as well as nonwoody plant species. There was no gradational change in the herbaceous cover or shrub density in the landward direction of the transition zone. However, tree density, basal area, and canopy cover increased

Table 8. Number of sample plots in each vegetation zone by site.

Site Number	Number of Plots Sampled Low Marsh	High Marsh	Transition	Forest	Ground-Water Seep
2	2	4	1	3	0
3	2	4	1	3	0
5	2	0	0	3	2
8	2	0	1	1	0
9	0	3	1	3	0
10	1	0	3	0	0
11	0	0	2	1	0
11b	0	2	1	0	0
12JA	2	2	2	0	0
12JB	0	2	2	1	0
BFF	0	2	2	3	0
BSN	2	1	2	3	0
12T	2	0	1	1	0
13	2	1	2	2	0
13H	2	2	2	0	0
17	2	2	0	0	0
18	2	1	2	0	0
21	2	0	2	3	0
21B	2	2	1	0	0
22	1	1	3	2	0
26	2	1	1	3	0
27	2	3	0	0	2
28	2	1	0	0	0



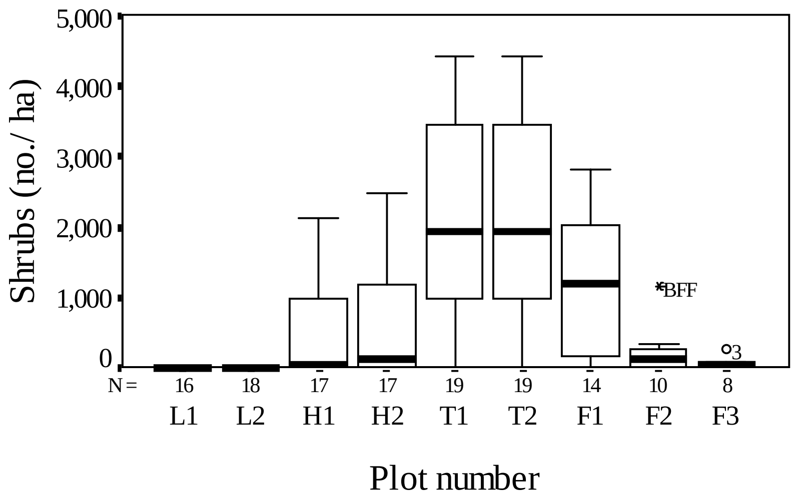
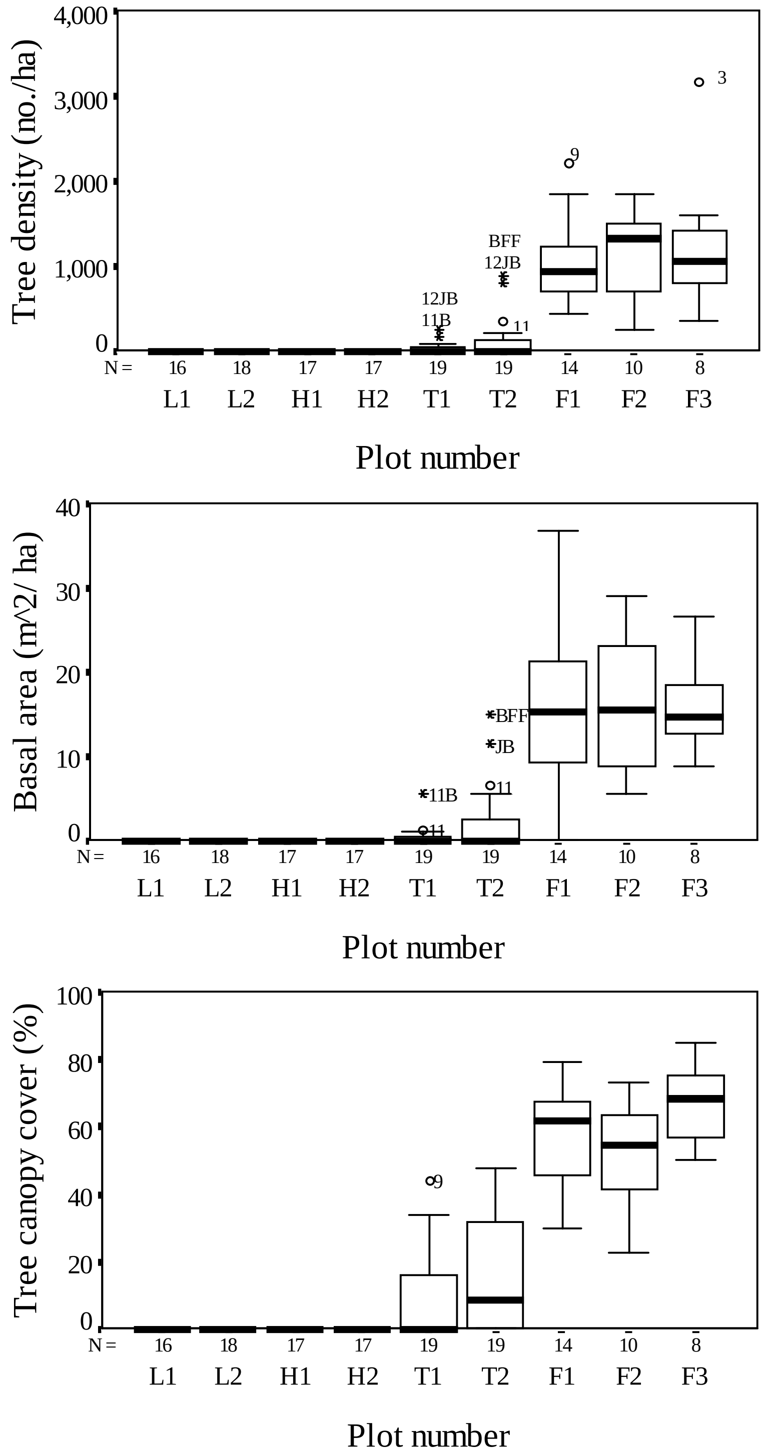


Figure 17. Boxplots showing physical components of vegetation structure along a gradient from low marsh to forest. Shrubs included *Pinus* and *Juniperus* with dbh <10 cm and all members of the following genera: *Iva* , *Baccharis*, *Myrica*, and *Vaccinium*. The solid center line indicates the median, the upper and lower edges of the box represent the 1st and 3rd quartiles, and the top and bottom whiskers represent the minimum and maximum values except when outliers or extremes are present. Outliers are indicated with open circles and represent cases with values between 1.5 - 3.0 box lengths from the upper or lower box edge. Extremes are indicated with a star and represent cases with values >3.0 box lengths from the upper or lower box edge. Outliers and extremes are labeled with their corresponding site number.

Figure 17. Continued



landward towards the forest. The herbaceous stratum was sparse and shrub density was low in the forest zone. Instead this zone was dominated by trees with an average basal area of 17 m^2/ha and canopy cover of 58 %. In a landward direction within the forest, tree density decreased, basal area decreased in range, and canopy cover increased.

There were several outliers and extremes in each physical structure component of the vegetation. Although several sites deviated from others for a single component in a single plot or zone; a few sites exhibited several abnormalities. Site 11B had a consistently higher herbaceous cover in its high marsh zone and had a higher than average density and basal area in its T1 plot. Sites 12JB and BFF had higher tree densities and basal area in their transition zones. Moreover, BFF had a higher shrub density in its F1 plot. Finally, site 11 had a lower herbaceous cover in its T2 plot and a higher than normal tree density and basal area in its transition zone.

Species richness increased from the low marsh to the forest; with a total of 44 species found among all plots sampled (Table 9). Of these species, only 5 were found in the low marsh, 17 in the high marsh, 23 in the transition, and 34 in the forest plots. Table 10 summarizes the relative percent ground cover of each of these species, and Table 11 lists the importance values for woody species. Importance values (IV) were calculated differently for the forest and the other three zones because basal area is relatively low in the first three zones and much higher in the forest. For the low marsh, high marsh, and transition zones, IVs are equivalent to the average relative density for species >1m. Forest

Table 9. Plant species present in the four vegetation zones. Presence is indicated by an X and species are listed below their family name. Species nomenclature follows Radford et al. (1968).

Family *Species*	**Low marsh**	**High marsh**	**Transition**	**Forest**
Poaceae				
Spartina alterniflora	X	X	X	
Spartina patens	X	X	X	
Distichlis spicata	X	X	X	X
Panicum virgatum		X	X	X
Setaria viridis		X	X	X
Phragmites australis		X	X	
Juncaceae				
Juncus roemerianus		X	X	X
Juncus gerardi		X	X	
Cyperaceae				
Scirpus sp.		X	X	
Plumbaginaceae				
Limonium carolinium	X	X	X	X
Chenopodiaceae				
Salicornia spp.	X	X	X	
Atriplex patula		X	X	X
Typhaceae				
Typha sp.			X	
Asclepiadaceae				
Asclepias incarnata			X	X
Apiaceae				
Hydrocotyle sp.				X
Anacardiaceae				
Rhus radicans			X	X
Bignoniaceae				
Bignonia capreolata				X
Vitaceae				
Parthenocissus quinquefolia			X	X
Vitis sp.				X
Liliaceae				
Smilax bona-nox				X
Smilax rotundifolia				X
Ericaceae				
Vaccinium corymbosum				X

Table 9. Continued

Family ***Species***	**Low marsh**	**High marsh**	**Transition**	**Forest**
Asteraceae		X	X	X
Iva frutescens				
Baccharis halimifolia		X	X	
Erechitites hieracifolia			X	
Borrichia frutescens		X		
Myricaceae				
Myrica cerifera			X	X
Cupressaceae				
Juniperus virginiana		X	X	X
Pinaceae				
Pinus taeda			X	X
Pinus serotina			X	X
Rosaceae				
Prunus serotina				X
Aquifoliaceae				
Ilex opaca				X
Ilex sp.			X	
Aceraceae				
Acer rubrum				X
Nyssaceae				
Nyssa sylvatica				X
Ulmaceae				
Celtis occidentalis				X
Hamamelidaceae				
Liquidambar styraciflua				X
Lauraceae				
Persea borbonia				X
Araliaceae				
Aralia spinosa				X
Oleaceae				
Ligustrum sp.				X
Fagaceae				
Quercus phellos				X
Quercus falcata				X
Magnoliaceae				
Liriodendron tulipifera				X
Magnolia virginiana				X
TOTALS 44	**5**	**17**	**23**	**34**

Table 10. Relative percent ground cover (0-1m) of species or other cover type in each vegetation zone. Species without at least 1% relative cover were not reported.

Cover Type or Species	**Plot Number**								
	L1	**L2**	**H1**	**H2**	**T1**	**T2**	**F1**	**F2**	**F3**
n =	**48**	**54**	**63**	**63**	**60**	**60**	**42**	**30**	**24**
Spartina alterniflora	43	48	2	3	1	1			
Spartina patens	1	7	40	38	22	22			
Distichlis spicata	4	12	28	27	10	7			
Salicornia spp.	6	3							
Borrichia frutescens			1						
Juncus geradi			3	3	7				
Iva frutescens			5	5	18	14			
Setaria viridis			1	1		2			1
Limonium carolinium			1	1		1	1		
Juncus roemerianus			7	15	4	4			1
Baccharis halimifolia				1	1	4			
Panicum virgatum					4	7	1	5	1
Phragmites australis					1	1			
Typha sp.					1	1			
Myrica cerifera					3	3	5	1	1
Juniperus virginiana						1	3		
Pinus taeda						2	2		4
Erechtites hieracifolia							2		
Liquidambar styraciflua							1	1	
Rhus radicans							4	4	2
Bignonia capreolata							2	3	6
Smilax bona-nox							3	6	2
Asclepias incarnata							1		1
unidentified graminoid							2		1
Persea borbonia							1		1
Atriplex patula								1	
Smilax rotundifolia								1	
Quercus phellos								1	
Ilex opaca								1	
Celtis occidentalis								1	
Hydrocotyle sp.									1
Parthenocissus quinquefolia									1
Vitis sp.									1

Table 10. Continued

Cover Type	Plot Number								
	L1	**L2**	**H1**	**H2**	**T1**	**T2**	**F1**	**F2**	**F3**
Bare ground	38	30	5	3	7	6	1		3
Wrack	3		3	2	4	6	1		
Pothole	3		3	2	2				
Crab burrow	2						3		
Dead shrub				1	1	1			
Stump					1	1			
Dead tree					1	1			1
Litter					8	15	57	67	64
Woody debris					3	1	12	9	11
Vegetated Total	**54**	**70**	**88**	**92**	**74**	**68**	**26**	**24**	**22**
Unvegetated Total	**46**	**30**	**11**	**8**	**26**	**31**	**73**	**76**	**78**
Grand Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 11. Importance values (IV) for woody species in the four vegetation zones for all field sites. IVs were calculated differently depending on the zone. Low marsh, high marsh, and transition IVs are equivalent to their average relative density (species >1m tall). Forest IVs were calculated by averaging relative density and basal area for species > 1m, by plot. A sum of less salt tolerant species (LST) occurring in the transition zone was calculated, and these species are indicated with *. All woody species occurring in the high marsh were salt tolerant, and all species occurring in the forest were salt intolerant. Species without at least 1 % relative importance were not reported.

	Plot Number								
Species	**L1**	**L2**	**H1**	**H2**	**T1**	**T2**	**F1**	**F2**	**F3**
n=	**16**	**18**	**21**	**21**	**20**	**20**	**14**	**10**	**8**
Iva frutescens			41	42	60	42			
Baccharis halimifolia				5	12	17	1	1	
*Myrica cerifera**					12	14	12	3	1
*Juniperus virginiana**					13	19	21	2	5
*Pinus taeda**					4	7	33	38	34
Prunus serotina							3	5	11
Ilex opaca							3	9	12
Nyssa sylvatica							4	10	12
Celtis occidentalis							14	16	1
Liquidambar styraciflua							3	1	9
Liriodendron tulipifera							1	6	7
Aralia spinosa							1	5	3
Persea borbonia								1	2
Quercus falcata									2
LST species (*)					**29**	**40**			
Hardwood IV	**0**	**0**	**0**	**0**	**0**	**0**	**29**	**53**	**59**
TOTAL	**0**	**0**	**41**	**47**	**100**	**100**	**96**	**100**	**100**

IVs were calculated by averaging the relative density and relative basal area of each species >1 m tall by plot.

The low marsh was dominated by a single halophytic grass species, *Spartina alterniflora*, in addition to having a large portion of bare ground. *Salicornia* spp. and *Distichlis spicata* were the next most prevalent yet neither of these covered more than an average 6 % of the ground in the L1 plots. *D. spicata* was 8% higher, in average importance, in the plots farther inland (L2). Overall, the importance of vegetated ground cover was 16 % higher in L2 than L1.

The high marsh was dominated by *S. patens* and *D. spicata*, and the percentage of unvegetated ground cover was low (8-11 %), relative to the low marsh (30-46 %). *Juncus roemerianus* was the next most prevalent species; however, it did not cover more than an average of 15 % of either high marsh plots. Although there were a number of other species present in this zone, none had >5 % cover, on average. There did not appear to be any significant differences in vegetation characteristics between the H1 and H2 plots.

Two grasses (*S. patens, D. spicata*) and one shrub (*Iva frutescens*) were the predominate plant species in the transition zone. The percentage of bare ground cover was similar to the high marsh, although there was an additional type of unvegetated ground cover in the form of leaf litter. Vegetated ground cover was 6 % lower, and unvegetated ground cover was 6% higher in T1 than T2. The percentage of less salt tolerant genera (*Panicum, Setaria, Pinus, Juniperus*) was slightly higher (8 %) in T2 than

T1, and the percentage of salt tolerant genera (*Spartina*, *Distichlis*, *Juncus, Iva*) was slightly lower (8%) in T2 than T1.

The forest ground cover was composed primarily of leaf litter and woody debris with only an average of 22-26 % vegetated cover. The species composition was rather variable with no single species dominating. The only salt tolerant species with at least 1 % average relative cover was *L. carolinium* and it was located in the most seaward forest plot (F1).

The low marsh zone had no shrubs or trees in any plots. *I. frutescens* was the most important woody species in the high marsh. However, it was not present in all high marsh sites. *I. frutescens* was also the most important woody species in the transition zone, although its degree of importance decreased landward. *B. halimifolia*, *M. cerifera*, and *J. virginiana* were similar in importance for the transition, and all were more important in T2 than T1. *P. taeda* had the lowest IV in the transition zone, but was similar to *J. virginiana* in that it was more important in T2 plots than T1 plots. *P. taeda* was the most important species in all three forest plots, and the remaining species showed variation across the plots. *J. virginiana* and *M. cerifera* were relatively important in F1 but were very unimportant in the two landward plots. In general, hardwood species importance increased with increasing distance from the marsh (Table 11). Specifically, *C. occidentalis* showed a relative importance in both F1 and F2 but was negligible in F3. In contrast, the hardwood tree species *P. serotina, I. opaca, N. sylvatica, L. styraciflua, Q. falcata*, and *L. tulipifera* all increased in importance with increased distance from marsh.

With the exception of three extreme sites, the low marsh had no dead shrubs or trees, but had stumps in its landward plot (Figure 18). The high marsh had the most dead short shrubs (<1 m) of the four zones. Short shrub (<1 m) density was higher in the landward plot of the high marsh. In contrast, the high marsh had very few dead trees, tall shrubs (>1 m), or stumps. The transition zone had a low number of dead shrubs (<1 m) but the largest number of dead shrubs (>1 m) in its seaward plot. The transition zone also had the largest number of dead trees and was second to the forest in stump density. The forest had no dead shrubs, and a few dead trees. Both dead tree and stump density increased away from the marsh.

There were a number of outliers and extremes for all dead components and several sites in particular were deviant in several zones or vegetative components. Site 12JA had higher than average shrub (<1 m) densities in its low marsh, high marsh, and transition zones; shrub (>1 m) densities in its high marsh zone; tree densities in its high marsh and transition zones; and stump densities in its low marsh and high marsh zones. Site 10 differed from the average in its low marsh zone by having higher shrub (<1 m) and tree densities. Sites 12T, 13H, 21 and 22 had higher dead shrub densities (both sizes) in their transition zones. Furthermore, stump densities were higher for 13H in its high marsh zone and for 12T in its transition zone. Site BFF had a higher than average dead tree density in its high marsh zone and more stumps in its transition zone. Finally, site 12JB had a high dead tree and stump density in its F1 plot.

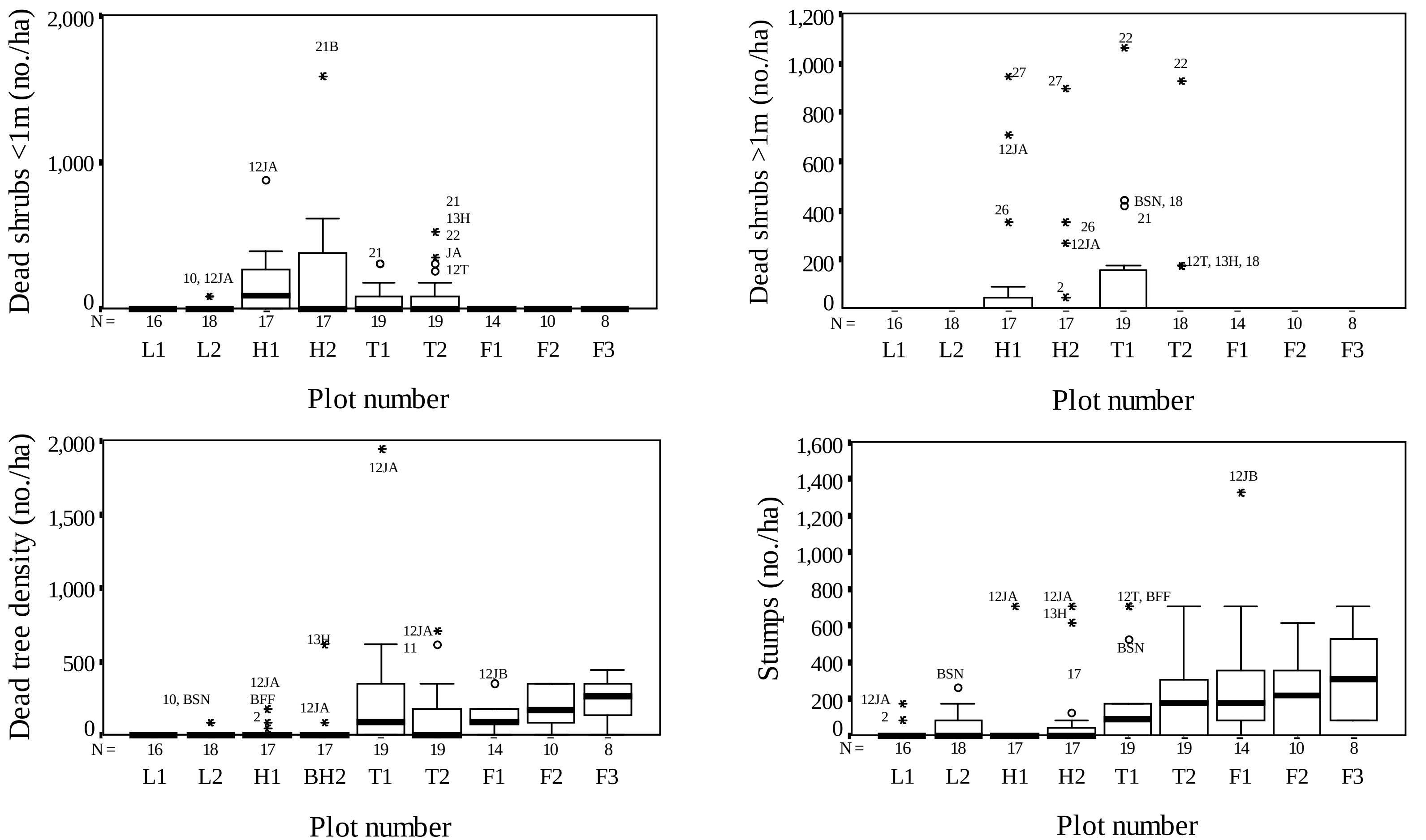


Figure 18. Boxplots showing dead vegetation components along a gradient from low marsh to forest. Boxplot components are described in Figure 17.

All low marsh zones were mapped as Chincoteague soils, but soil profile descriptions showed that not all sites were identical in the field (Table 12). Most (78 %) of the low marsh soils had an organic rich horizon, and 71 % of these had O horizons $\geq$30 cm deep. The depth of the organic rich horizon ranged from 0 to >100 cm in both the L1 and L2 sample plots; however, the median was lower by almost 40 cm in the landward plot (L2) (Figure 19). The extent of decomposition in the low marsh O horizon ranged from low (fibric peat) to high (sapric muck). The range in percent organic matter content was similar for the soil surface and subsurface (2 - 43 %), but the median was much lower for the subsurface soils (Figure 20). For all sites, low marsh soils had indicators of reduced conditions (i.e. chromas < 2) and soils at six of the sites were mottled. The only noticeable difference between low marsh soils forming adjacent to different forest soil types was that the few sites with a B horizon, in the upper 40 cm, were located next to forests with nonhydric soils. The texture of the mineral soil ranged from loamy sand to sandy clay, although most of the soils were predominately loamy. The low marsh had the highest salinities of the four vegetation zones (Figure 21). Salinity range was similar for the soil surface (6-36 ppt) and subsurface (2-29 ppt), but the salinity median of the subsurface soil was much lower.

Most high marsh soils were mapped as Magotha, but there were three sites that lacked this hydric soil series and still had the high marsh zone. Two of these sites (BSN, 26) had a very narrow (<9 m) high marsh zone. There were a total of sixteen sites with high marsh, and all but four of these had an organic rich horizon (Table 13). Within the high marsh, the depth of the O horizon ranged from 3 to >100 cm, and did not differ

Table 12. Low marsh soil profile characteristics. Values for mottle abundance range from 1-3 with 3 representing the most mottles.

Map Soil Series	Forest Soil Series	Site #	Horizon	Depth (cm)	Texture or Degree of Decompositon	Matrix Hue/Value /Chroma	Mottle Hue/Value /Chroma	Mottle Abundance	Organic Matter (%)	Salinity (ppt)
ChA	NmA	2	A	0 - 30	Sandy loam	10YR 4/1	10YR 6/8	3	7.9	15.0
			E	30 - 60	Loamy sand	10YR 6/2	10YR 5/1	3	2.9	6.3
							10YR 6/4	3		
		3	A	0 - 40	Silt	5B 4/1			21.9	20.0
			O	40 - 70	Fibric peat	10YR 3/1			30.2	21.2
		10	O/A	0 - 15	Sandy loam	10YR 3/1			11.9	15.8
			A	15 - 40	Sandy clay	5B 4/1	10YR 3/1	3	1.9	2.4
		21	O1	0 - 20	Fibric peat	10YR 3/2			47.3	18.3
			O2	20 - 90	Sapric muck	10YR 3/2			41.2	17.4
			A	90 - 100	Silty loam	10YR 2/0				
	DrA	22	O/A	0 - 60	Peaty Silt	2.5G 2/0			24.0	19.2
			A	60 - 80	Loam	2.5G 2/0			16.4	14.4
			E	80 - 100	Loam	10YR 4/1				
		26	O1	0 - 50	Fibric peat	10YR 3/2			45.5	19.1
			O2	50 - 90	Sapric muck	10YR 2/0			38.7	21.7
			A	90 - 100	Loam	10YR 2/1				
	MuA	BSN	O	0 - 10	Fibric peat	10YR 3/2			30.9	18.1
			A	10 - 40	Silt loam	5B 4/1			2.2	2.7
		12JA	A1	0 - 15	Silty loam	10YR 4/1	10YR 5/8	3	8.4	11.8
							10YR 2/1	3		
			A2	15 - 33	Silty loam	10YR 2/1	10YR 4/1	1	7.8	4.7
			B	33 - 50	Sandy loam	2.5Y 4/3				

Table 12. Continued.

Map Soil Series	Forest Soil Series	Site #	Horizon	Depth (cm)	Texture or Degree of Decomposition	Matrix Hue/Value /Chroma	Mottle Hue/Value /Chroma	Mottle Abundance	Organic Matter (%)	Salinity (ppt)
ChA	MuA	13H	A	0 - 10	Clay Loam	10YR 6/1	10YR 6/8	3	3.1	5.6
			B	10 50	Clay Loam	10YR 6/4	10YR 6/8	3	3.0	3.9
		17	O	0 - 70	Sapric muck	10YR 3/1			26.4	36.2
			A	70 - 90	Sandy loam	10YR 5/1			4.4	8.2
	BkA	5	O	0 - 100	Sapric muck	10YR 3/2			18.1	19.5
									20.6 *	14.9 *
		8	A	0 - 15	Loamy sand	10YR 3/1			6.7	12.4
			B	15 - 40	Loamy sand	10YR 5/3	10YR 3/1	3	2.3	7.9
		18	O	0 - 35	Fibric peat	10YR 3/2			31.8	35.2
			A	35 - 50	Sandy loam	10YR 2/0			4.8	1.5
		21B	O	0 - 45	Sapric muck	10YR 2/1			42.8	16.3
			A	45 - 60	Loam	10YR 2/0			9.1	6.8
	BoA	12T	O	0 - 9	Fibric peat	5GY 4/1			9.8	11.5
			A	9 - 40	Sandy loam	5GY 4/1			3.0	7.3
		13	O	0 - 10	Peaty silt	5B 4/1	2.5Y 8/6	3	7.8	12.9
			A	10 - 30	Silty loam	10YR 2/1	2.5Y 8/6	3	4.5	5.9
	MoD	27	O1	0 - 15	Fibric peat	10YR 3/2			32.9	21.9
			O2	15 - 100	Sapric muck	10YR 2/0			33.6	29.2
		28	O	0 - 30	Fibric peat	10YR 3/2			16.8	16.7
			A	30 - 50	Silty loam	5B 4/1			13.0	19.1

* Organic matter (%) and salinity (ppt) determined between 15 - 25 cm

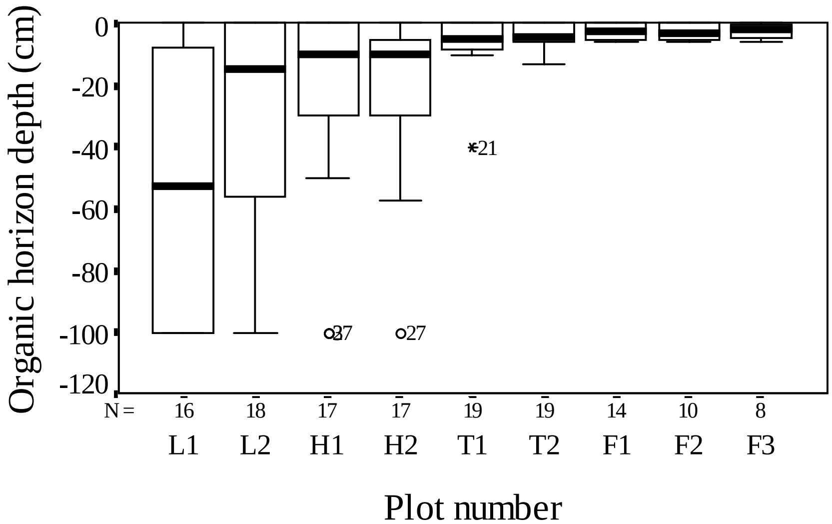


Figure 19. Boxplots showing depth of the organic rich horizon (cm) in each sample plot. Boxplot components are described in Figure 17.

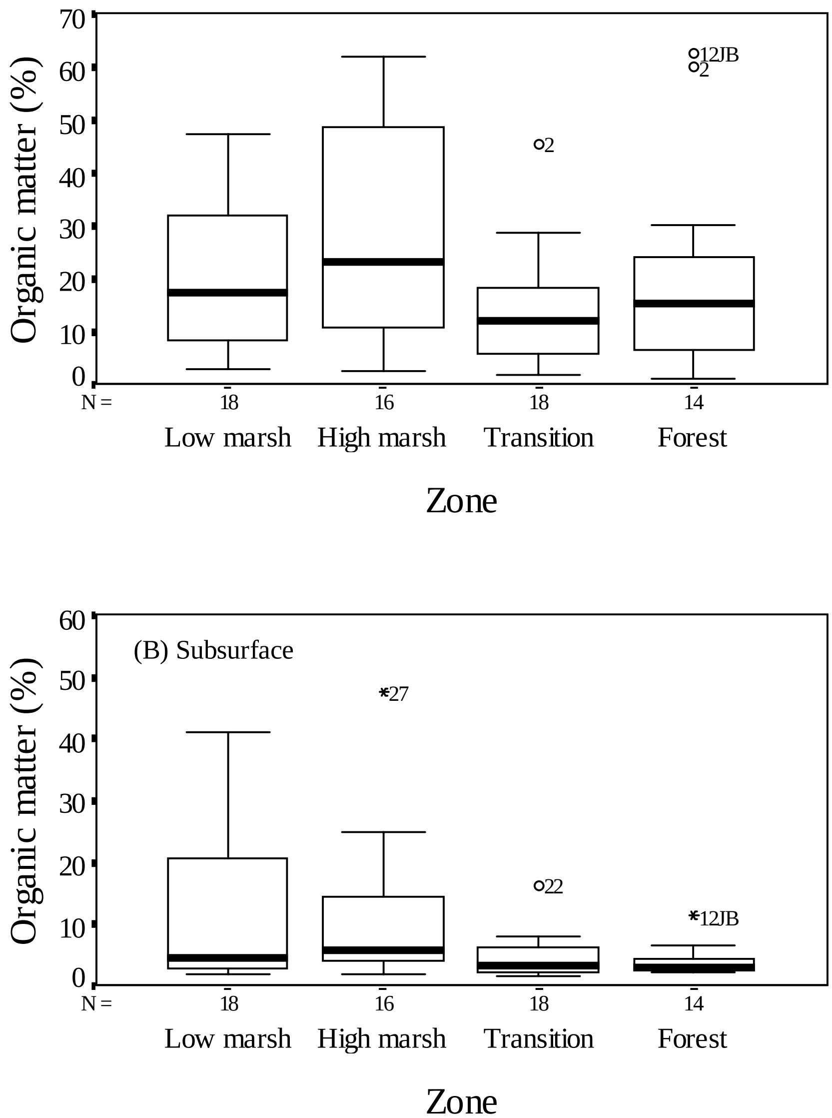


Figure 20. Boxplots showing the organic matter (%) of the soil (A) 0-10 cm and (B) subsurface (first 10 cm of the next deeper horizon), for each vegetation zone. Boxplot components are described in Figure 17.

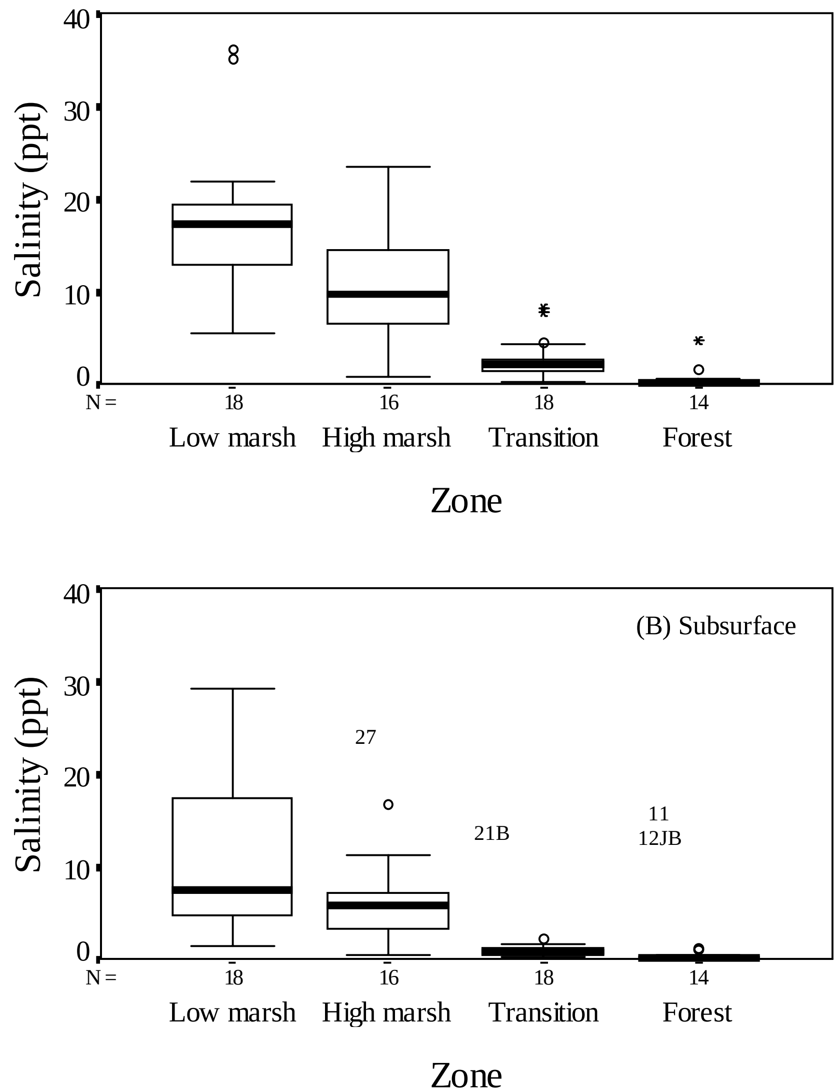


Figure 21. Boxplots showing salinity (ppt) of the soil (A) 0 - 10 cm and (B) subsurface (first 10 cm of the next deeper horizon), for each vegetation zone. Boxplot components are described in Figure 17.

Table 13. High marsh soil profile characteristics. Values for mottle abundance range from 0-3 with 3 representing the most mottles.

Map Soil Series	Forest Soil Series	Site #	Horizon	Depth (cm)	Texture or Degree of Decomposition	Matrix Hue/Value/ Chroma	Mottle Hue/Value /Chroma	Mottle Abundance	Organic Matter (%)	Salinity (ppt)
ChA	NmA	9	O	0 - 45	Sapric muck	10YR 3/2			54.3	9.2
			A	45 - 60	Sandy loam	10YR 2/1			10.8	6.6
	DrA	26	O	0 - 15	Fibric peat	10YR 3/2			61.9	14.6
			A	15 - 40	Sand	10YR 5/1			4.9	2.9
	MuA	BSN	O	0 - 10	Sapric muck	10YR 3/2			15.1	14.6
			A	10 - 40	Silty loam	10YR 3/1			5.8	6.0
MaA	NmA	2	O	0 - 8	Fibric peat	10YR 3/1			21.7	10.2
			A	8 - 20	Sandy loam	10YR 2/1			5.8	6.1
			E	20 - 40	Loamy sand	10YR 6/2	10YR 6/4	3		
		3	O	0 - 40	Fibric peat	10YR 3/1			24.6	23.6
			O/A	40 - 50	Peaty loam	10YR 3/1			18.8	8.0
			A	50 - 60	Sandy clay loam	10YR 2/1				
		12JB	O	0 - 11	Fibric peat	10YR 3/1			47.6	8.8
			A	11 - 30	Silty clay	10YR 2/1	10YR 6/1	1	24.8	7.2
		BFF	O	0 - 10	Fibric peat	10YR 3/2			33.7	12.4
			A	10 - 20	Silty loam	10YR 2/1	10YR 5/1	1	15.7	4.2
			E	20 - 40	Silty loam	10YR 5/1				
	DrA	11B	O	0 - 40	Fibric peat	10YR 3/2			59.5	21.1
			A	40 - 60	Silty loam	10YR 4/1			10.2	7.3
		22	O/A	0 - 30	Peaty silt	2.5G 2/0	10YR 2/1	2	15.8	14.4
			A	30 - 70	Silt	2.5G 2/0	10YR 2/1	2	13.4	11.3

Table 13. Continued.

Map Soil Series	Forest Soil Series	Site #	Horizon	Depth (cm)	Texture or Degree of Decomposition	Matrix Hue/Value/ Chroma	Mottle Hue/Value /Chroma	Mottle Abundance	Organic Matter (%)	Salinity (ppt)
MaA	MuA	13H	A	0 - 10	Loam	10YR 3/1			9.3	7.1
			E	10 - 40	Loam	10YR 6/1	10YR 6/3	3	3.4	2.5
		17	A1	0 - 10	Sandy loam	10YR 5/1			2.5	0.9
			E	10 - 30	Sandy loam	2.5Y 6/2			1.9	0.8
			B	30 - 50	Sandy loam	2.5Y 6/4				
	BoA	13	O	0 - 3	Peaty loam	10YR 2/2			12.2	6.2
			A	3 - 15	Loam	10YR 4/1	10YR 2/1	2	5.1	4.0
			E	15 - 40	Loam	10YR 6/1	2.5Y 6/8	3		
	BkA	18	O	0 - 20	Fibric peat	10YR 3/2			42.0	21.3
			A	20 - 35	Sandy loam	10YR 2/1			6.0	5.7
			B	35 - 50	Sandy loam	10YR 6/3	10YR 2/1	3		
		21B	A	0 - 25	Sandy loam	10YR 2/1			8.6	3.3
			B	25 - 40	Sandy loam	2.5Y 6/6	10YR 2/1	1	1.9	5.8
	MoD	27	O1	0 - 15	Fibric peat	10YR 3/2			50.2	8.7
			O2	15 - 100	Sapric muck	10YR 2/0			47.8	16.9
		28	A	0 - 15	Sandy loam	10YR 4/2			5.4	2.6
			B	15 - 40	Sandy clay loam	10YR 6/4	10YR 4/2	2	1.9	1.2

much along the sea to land gradient (Figure 19). The degree of the decomposition in the O horizon of high marsh soils varied from low (fibric) to high (sapric) as did percent organic matter in both the soil surface (2.5 - 62 %) and soil subsurface (2 - 48 %) horizons (Figure 19). High marsh soils at all sites sampled displayed signs of reduced conditions (chroma <2) and soils at nine of the sites were mottled. Four of the sites had B horizons within 35 cm of the soil surface and all of these occurred in marshes adjacent to uplands. The texture of the mineral soil ranged from sand to sandy clay loam; however, the majority of the soils were predominately loam. Soil salinity of the high marsh was lower than in the low marsh but higher than the other two zones. Salinity ranged from 0.9-23.6 ppt in the soil surface and from 0.6-16.9 in the subsurface (Figure 21). With exception for site 18, high marsh zones forming seaward of uplands had lower salinities than those forming seaward of wetlands.

Transition vegetation zones were present at 18 sites, and most (13) of these developed over the transition between the MaA and forest soil series (Table 14). Fifty percent of the transition sites had soils with organic rich horizons; however, the depth of the horizon was much shallower than those in either the low or high marsh zones (Figure 19). There was no change in O horizon depth from the T1 to T2 plot. Similar to the other two marsh zones, the degree of decomposition varied from low to high (fibric peat to sapric muck). Percent organic matter of the soil was lower for the transition zone (14.8 % surface average) than the other two marsh zones, and this percentage decreased in the soil's subsurface to an average of <5 %. Soils at all of the sites had indicators of reduced conditions (chroma <2) and soils at 50 % of the sites were mottled. Nine of the sites had

Table 14. Transition soil profile characteristics. Values for mottle abundance range from 0 - 3 with 3 representing the most mottles.

Map Forest- Marsh Soil Series	Site #	Horizon	Depth (cm)	Texture or Degree of Decomposition	Matrix Chroma	Matrix Hue/Value/ Chroma	Mottle Hue/Value/ Chroma	Organic Matter (%)	Salinity (ppt)
NmA	11	A	0 - 15	Sandy loam	10YR 4/1			7.5	2.6
		E	15- 40	Sandy loam	10YR 5/2	10YR 4/1	1	3.6	0.9
NmA - MaA	2	O	0 - 6	Fibric peat	10YR 3/1			45.7	1.5
		A	6 - 21	Sandy loam	10YR 4/1			7.6	0.7
		B	21 - 40	Sandy loam	10YR 6/3	10YR 4/1	3		
	3	O	0 - 5	Fibric peat	10YR 3/1			14.9	1.6
		A	5 - 20	Sandy loam	10YR 5/1	10YR 6/8	1	3.0	0.4
		B	20 - 40	Sandy loam	10YR 6/6	10YR 6/8	2		
	10	A	0 - 15	Sandy loam	10YR 4/1	2.5 Y6/2	1	4.5	1.4
		E	15 - 40	Sandy loam	2.5 Y6/2	10YR 6/8	3	2.2	1.0
	12JB	O	0 - 6	Fibric peat	10YR 2/1			28.9	4.6
		A	6 - 20	Silt loam	10YR 2/1	10YR 5/1	2	8.1	1.1
		E	20 - 40	Loam	10YR 6/1	10YR 4/4	3		
	BFF	A	0 - 8	Silt loam	10YR 3/1			11.0	1.1
		E	8 - 30	Silt loam	10YR 5/1			3.6	0.6
	21	O	0 - 10	Mucky sandy loam	10YR 4/1			17.5	7.8
		A	10 - 40	Sandy loam	10YR 4/1			3.9	1.7
NmA - ChA	9	O	0 - 5	Fibric peat	10YR 3/2			15.0	2.7
		A	5 - 35	Sandy loam	10YR 4/1			2.9	0.7
		E	35 - 50	Loamy sand	10YR 6/1				
DrA - MaA	11B	O	0 - 5	Peaty loam	10YR 3/1			26.0	2.7
		A	5 - 40	Loam	10YR 4/1	10YR 6/4	3	5.2	1.0

Table 14. Continued.

Map Forest- Marsh Soil Series	Site #	Horizon	Depth (cm)	Texture or Degree of Decomposition	Matrix Chroma	Matrix Hue/Value/ Chroma	Mottle Hue/Value/ Chroma	Organic Matter (%)	Salinity (ppt)
DrA - MaA	22	A	0 - 15	Silt loam	10YR 3/1			9.6	8.2
		B1	25 - 35	Silt loam	2.5Y 5/4			2.8	0.8
		B2	35 - 50	Sand	2.5Y 5/4				
DrA - ChA	26	O	0 - 10	Sapric muck	10YR 3/2			18.2	2.7
		A	10 - 15	Loamy sand	10YR 4/2			7.5	0.4
		E	15 - 40	Loamy sand	10YR 5/1				
MuA - MaA	13H	O	0 - 3	Sapric muck	10YR 2/1			10.9	0.8
		A	3 - 10	Loam	10YR 4/1			2.6	0.6
		B	10 - 40	Loam	2.5Y 6/4				
MuA - ChA	BSN	A	0 - 10	Sandy silt loam	10YR 4/1			5.1	2.0
		B	10 - 30	Sandy silt loam	10YR 4/3			1.9	1.0
BoA - MaA	12T	A	0 - 40	Fine sandy loam	10YR 3/2			13.3	4.4
		B	40 - 50	Fine sandy loam	2.5Y 6/4	10YR 2/1	1	6.2	1.2
	13	O	0 - 4	Sapric muck	10YR 2/2			11.1	1.9
		A	4 - 15	Sandy loam	10YR 4/1	10YR 2/1	1	3.4	1.3
		E	15 - 40	Sandy loam	10YR 6/1	2.5Y 6/6	2		
BkA - MaA	18	A	0 - 15	Sandy clay loam	10YR 3/2			5.1	2.1
		B	15 - 40	Sandy loam	10YR 6/3	10YR 3/2	3	2.1	1.3
	21B	A	0 - 15	Sandy loam	10YR 3/1			5.8	2.4
		B	15 - 40	Sandy loam	2.5Y 6/6			1.7	2.4
BkA - ChA	8	A	0 - 8	Loamy sand	10YR 5/2			1.8	0.3
		B	8- 40	Sandy clay loam	10YR 5/4			2.0	0.3

a B horizon within 40 cm of the soil surface, but unlike the other zones, not all of these horizons corresponded to soils forming adjacent to uplands. The texture of the mineral soil ranged from sand to sandy clay loam; the majority of the soils were predominately loam. Transition soil salinities were much lower than the other two marsh zones and ranged from 0.3-8.2 ppt in the surface and from 0.3-2.4 ppt in the subsurface (Figure 21). There was no a trend between transition soil salinity and the adjacent soil series type.

There were 14 forested sites; five of which were located on nonhydric soils (Table 15). Only six of these sites had soils with organic rich horizons; all were shallow (3 - 6 cm) and showed no variation in the depth between the three forest plots (Figure 19). The degree of organic decomposition within this horizon was fairly low (fibric peat) for most of the forest sites. Percent of forest soil organic matter ranged widely from 1-63 % for the soil surface and was half of that for the subsurface (2-30 %) (Figure 20). All sites displayed signs of reduced conditions within the A horizon at least, and eight sites had soil mottling. Six of the sites had B horizons within 40 cm of the soil surface and most of these occurred within nonhydric soil series. All six of these sites lacked the eluvial E horizon. The mineral soil texture ranged from sand to silty loam, with most of the sites being sandy loam. With exception for two sites (11, 12JB), both soil surface and subsurface salinities were <1 ppt (Figure 21). Both sites with higher salinities had hydric soil series.

Table 15. Forest soil profile characteristics. Values for mottle abundance range from 0 - 3 with 3 representing the most mottles.

Map Soil Series	Site #	Horizon	Depth (cm)	Texture	Matrix Hue/Value/ Chroma	Mottle Hue/Value /Chroma	Mottle Abundance	Organic Matter (%)	Salinity (ppt)
NmA	2	O	0 - 6	Fibric peat	10YR 2/1			60.0	0.4
		A	6 - 18	Sandy loam	10YR 4/1	10YR 4/2	1	3.1	0.2
		B	18 - 44	Sandy loam	2.5Y 6/3	10YR 4/1	2		
	3	O	0 - 3	Fibric peat	10YR 3/2			6.7	0.3
		A	3 - 20	Sandy loam	10YR 4/1			30.3	0.3
		E	20 - 40	Sandy loam	10YR 6/1	10YR 6/8	3		
	9	O	0 - 6	Fibric peat	10YR 3/2			9.3	0.1
		A	6 - 40	Sandy loam	10YR 4/1			4.1	0.2
	11	A	0 - 10	Sandy loam	10YR 2/1			20.7	4.7
		E	10 - 40	Sandy loam	10YR 5/2			5.8	1.3
	12JB	O	0 - 6	Fibric peat	10YR 3/1			62.7	1.7
		A	6 - 15	Silt loam	10YR 2/1			11.4	1.2
		E	15 - 40	Loam	10YR 5/1	10YR 2/1	2		
	BFF	A	0 - 8	Silt loam	10YR 2/1			24.2	0.8
		E	8 - 35	Silt loam	10YR 5/1	10YR 6/3	1	4.3	0.4
	21	O	0 - 4	Fibric peat	10YR 3/2			6.5	0.2
		A	4 - 10	Sandy loam	10YR 3/1			2.3	0.3
		E	10 - 40	Sandy loam	10YR 5/2	10YR 5/4	2		
DrA	22	A	0 - 10	Loam	10YR 4/1	10YR 4/3	2	6.6	0.3
		B	10 - 50	Loam	10YR 4/2	10YR 4/3	2	2.7	0.6

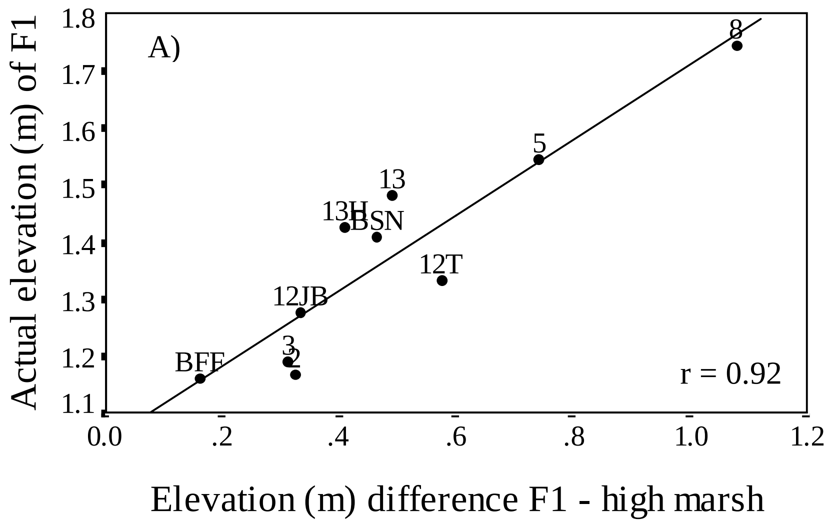
Table 15. Continued.

Map Soil Series	Site #	Horizon	Depth (cm)	Texture or Degree of Decomposition	Matrix Hue/Value/ Chroma	Mottle Hue/Value /Chroma	Mottle Abundance	Organic Matter (%)	Salinity (ppt)
DrA	26	O	0 - 5	Fibric peat	10YR 3/2			1.2	0.6
		A	5 - 10	Loamy sand	10YR 4/2	10YR 6/8	3	3.1	0.1
		E	10 - 40	Loamy sand	10YR 6/2	10YR 6/8	3		
MuA	BSN	A	0 - 6	Loam	10YR 4/1			13.1	0.1
		B	6 - 40	Loam	10YR 4/3			3.7	0.2
BkA	5	A	0 - 10	Sand	10YR 5/1			1.9	0.1
		B	10 - 40	Sand	10YR 5/4			2.2	0.1
	8	A	0 - 8	Sand	10YR 4/2			5.0	0.1
		B	8 - 30	Sand	10YR 5/3			3.0	0.1
BoA	12T	A	0 - 20	Sandy loam	10YR 3/2			21.3	0.3
		B	20 - 40	Sandy loam	10YR 5/4			3.0	0.2
	13	A	0 - 15	Sandy loam	10YR 3/2			17.5	0.1
		E	15 - 40	Sandy loam	2.5Y 6/2	2.5Y 6/6	3	2.3	0.1

Marsh potholes were present in both marsh zones and the transition but not the forest. Within zones, pothole formation was limited to sites where organic matter accumulated. However, not all sites with organic matter accumulation had marsh potholes. Two low marsh sites (21, 26), four high marsh sites (2, 3, 9, BFF), and one transition site (21) had marsh potholes within study plots. I observed potholes in low marsh site 27, and high marsh sites 11B and 27 but these potholes were not within the study plots. Pothole depth was limited to the depth of organic matter, but did not always penetrate as deeply as the organic matter.

Relative elevations of each sample point, determined using the laser level, were used to calculate slope and elevation differences along various positions within the site. The slope between L2 and F1 and the elevation difference between F1 and the average elevation of the high marsh, or the elevation of L2 for sites lacking a high marsh zone, had strong correlations to F1's elevation above MSL (Figure 22). These two variables were used to develop a multiple regression equation to predict F1's elevation above MSL (Figure 23) for sites lacking a permanent bench mark (Table 3). The multiple regression equation showed a stronger relationship (R^2 = 0.87) than either of the two predictor variables alone. Site 18 was the only site that lacked GPS data and a relative F1 elevation, and therefore none of its plots were related to MSL.

Predicted F1 values were used to tie the remainder of the plot elevations into MSL. Adding the predicted elevations to the actual elevation data set increased the variation a lot in the F3 plot but had little effect on the other plots (Figure 24). Elevation



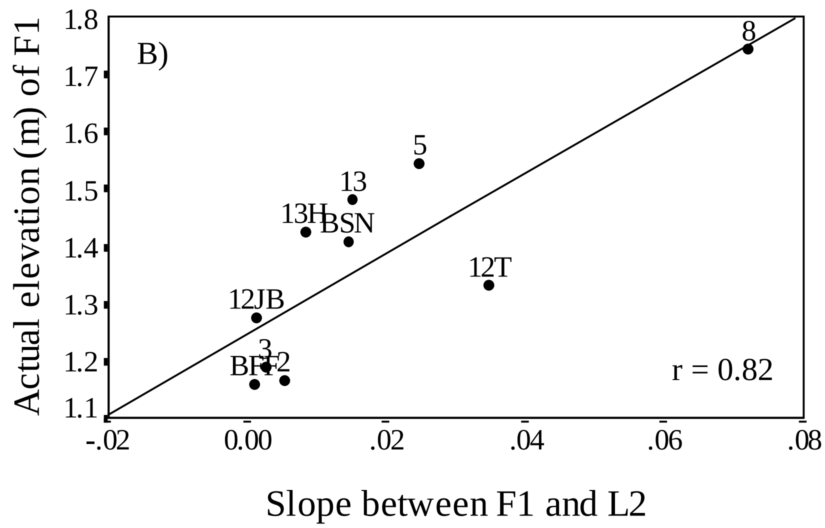


Figure 22. Scatter plots showing the relationship between F1's actual elevation and (A) the elevation difference between F1 and the average high marsh elevation, or L2 where the high marsh zone was absent, and (B) the slope between L2 and F1. Actual elevation is the elevation relative to MSL. Each point is labeled with its associated site.

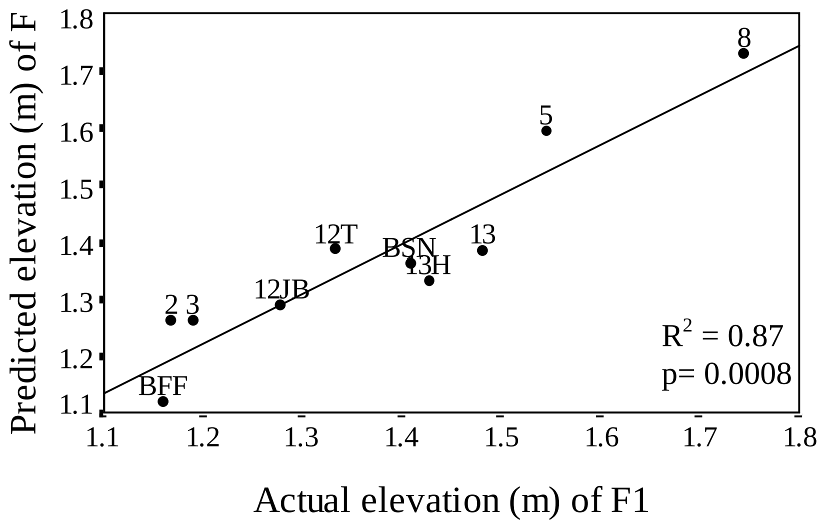


Figure 23. The relationship between predicted and actual elevations of F1. Actual elevations were determined using a GPS unit. Predicted elevations were determined using the following multiple regression equation:

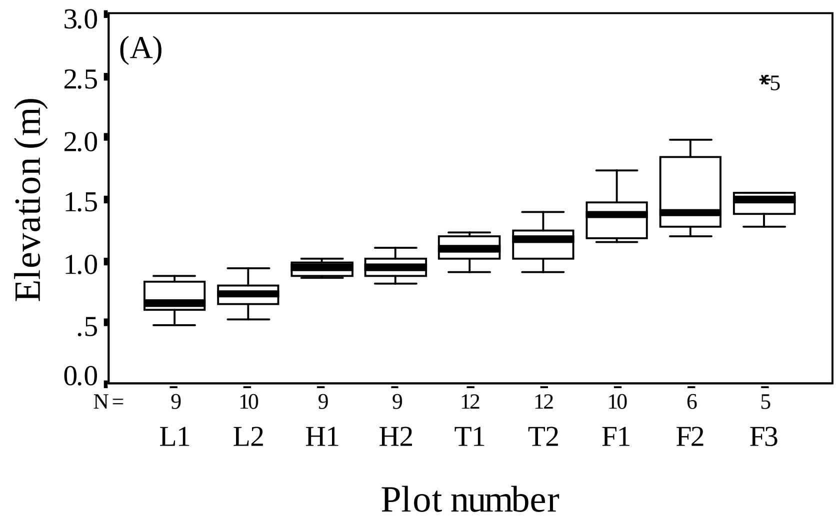
$$\text{predicted elevation} = 0.9837(X_1) - 4.1254(X_2) + 0.9667$$

where

X_1 = the difference in elevation between F1 and the average elevation of the high marsh zone, or L2 where the high marsh zone was absent, and

X_2 = the slope between L2 and F1.

Each point is labeled with its associated site.



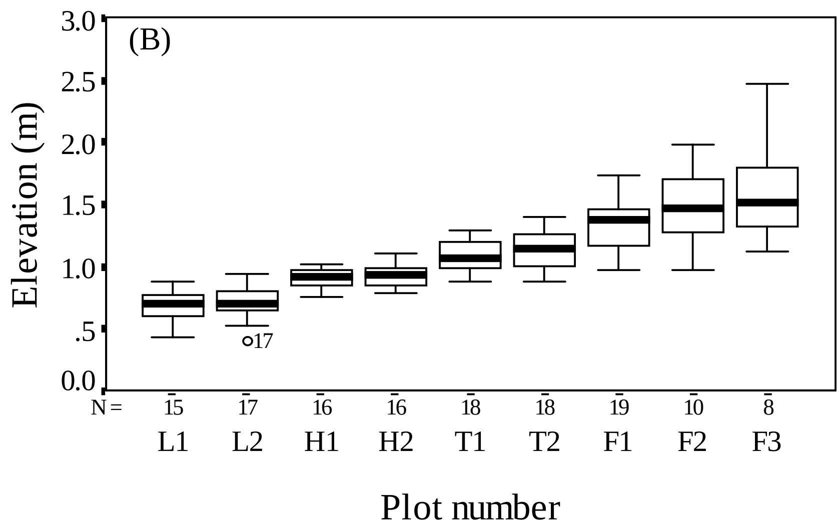


Figure 24. Boxplots showing (A) actual elevation (m) above MSL and (B) actual and estimated elevation (m) above MSL, along a gradient from low marsh to forest. Actual elevations are reported for sites with GPS data and estimated elevations are reported for sites lacking GPS data. Estimated elevations were calculated using the multiple regression equation shown in Figure 23. Boxplot components are described in Figure 17.

increased from low marsh to forest and was relatively similar within each zone (Table 16). Within-zone variation was highest for the forest and transition, and lowest for the high marsh. An overlap in elevation range existed between all zones. In general, the lower 25 % of each zone's sites overlapped in elevation with the more seaward zone and the upper 25 % of each zone's sites overlapped in elevation with the more landward zone (Figure 24). Between zone variation was largest between the forest and transition, with 0.38 m difference between the averages of each zone, and 0.245 m difference between F1 and the transition zone. Between zone variation was smallest between the transition and high marsh, with only 0.189 m separating them on average.

Two sites (5 and 27) had a similar zone that did not meet the criteria for any of the four described zones. For both sites, this zone appeared to be receiving groundwater discharge and hence will be referred to as a groundwater seep. For both sites, the groundwater seep was just seaward of the forest state. In terms of physical structure components, percent herbaceous cover in this zone was lower than the other marsh zones, there were a few shrubs for site 27 and none for site 5, and there were no trees at either site (Table 17A). Site 5 had low canopy cover due to shading by trees in the adjacent forest. Ground cover was dominated by *Phragmites australis* (44%) in site 5 and a fairly high proportion (29%) was unvegetated. In site 27, ground cover was distributed among three species (*Scirpus* sp., *Limonium carolinium*, and *Hibiscus* sp.), and this site, too, had a high portion of unvegetated ground cover (Table 17B). The typical marsh species (*S. alterniflora, S. patens, D. spicata*, or *J. roemerianus*) were rare in the groundwater seeps and the shrub *I. frutescens* was absent.

Table 16. Elevation averages for plots and zones, and elevation differences within plots and between zones. In order to illustrate the effects estimated elevations had on the data set variation, variables are shown for sites with GPS data and then for all sites combined. Average zone elevations were determined using each plot individually rather than high marsh and transition plot averages.

	GPS Sites Only				All Sites			
Plot #	Average plot elevation (m)	Within zone difference (m)	Average zone elevation (m)	Between zone difference (m)	Average plot elevation (m)	Within zone difference (m)	Average zone elevation (m)	Between zone difference (m)
L1	0.695				0.689			
		0.044	0.717			0.032	0.705	
L2	0.739				0.721			
				0.231				0.210
H1	0.940				0.903			
		0.015	0.948			0.026	0.915	
H2	0.955				0.929			
				0.177				0.189
T1	1.101				1.081			
		0.047	1.125			0.042	1.104	
T2	1.148				1.123			
				0.383				0.380
F1	1.374				1.349			
		0.139				0.144		
F2	1.513		1.508		1.493		1.484	
		0.123				0.116		
F3	1.636				1.609			

Table 17. Vegetation characteristics (A) physical structure, and (B) relative % ground cover (0-1m) and species IVs for groundwater seeps. Relative % cover is calculated same as Table 10 and IVs are calculated same as Table 11.

(A)

Physical Structure	**Site 5**	**Site 27**
Herbaceous cover (%)	59	46
Shrub density (no./ha)	0	1,061
Tree density (no./ha)	0	0
Basal area (m^2/ha)	0	0
Tree canopy cover (%)	9*	0

* canopy cover from adjacent forest zone

(B)

	Ground Cover %		**Importance Value**	
Cover Type or Species	**Site 5**	**Site 27**	**Site 5**	**Site 27**
Spartina alterniflora	5			
Spartina patens	5	2		
Distichlis spicata	5			
Phragmites australis	44			
Scirpus sp.		23		
Limonium carolinium		17		
Bignonia capreolata		2		
Hibiscus sp.		11		70
Baccharis halimifolia				30
Bare ground	29	43		
Litter	12			
Vegetated Total	**59**	**57**		
Unvegetated Total	**41**	**43**		
Grand Total	**100**	**100**	**0**	**100**

The elevations of the two groundwater seeps were higher than those of the low marsh, and lower than those of the high marsh, on average (Table 18). The slope was fairly steep at site 5 and very steep at site 27. For both sites, the groundwater seep occurred seaward of a very steep forest slope and was between 0.743 m and 0.818 m lower than the F1 plot. The groundwater seeps were not elevated much above the adjacent seaward state.

These seeps occurred in Magotha soils that were comprised in large part of organic matter (Table 18). Organic matter penetrated deep beneath the ground surface and was highly decomposed (sapric muck). Salinity was low (≤3 ppt) in the seeps for both sites but was high for both sites in the next seaward zone (site 5, 19.5 ppt; site 27, 8.7 ppt) (Tables 12 and 13).

4.3 Ecosystem State Classification

The sum of scores for the four variables used to describe the ability of the forest to resist state change to marsh (Table 4) was used to classify forest sites into three resistance groups: low (L), intermediate (I), and high (H). Sites with total scores between 0-2 were classified as low resistance; sites with total scores between 3-5 were classified as intermediate resistance; and sites with total scores of 6 or 7 were classified as high resistance. Based on the scoring procedure, seven forest sites were classified into the L resistance group; eight forest sites were classified into the I resistance group; and four forest sites were classified into the H resistance group (Table 19). The ranking procedure

Table 18. Elevation, zone width, and soil characteristics for groundwater seeps.

	Site 5	Site 27
Elevations and Zone Widths		
Elevation (m)	0.803	0.880
Zone slope	0.017	0.029
Elevation below adjacent forest (m)	0.743	0.818
Elevation above adjacent seaward zone (m)	0.148	0.053
Zone width (m)	24	15
Soil Characteristics		
Depth of organic matter (cm)	60	65
Organic matter (%)		
Surface (0-10cm)	20	43
Subsurface (10-20cm)	34	20
Salinity (ppt)		
Surface (0-10cm)	2.9	1.4
Subsurface (10-20cm)	3.0	0.7
Soil Series	MaA	MaA
O horizon depth (cm)	100	100
Degree of decomposition		
0 - 10 cm	Sapric muck	Fibric peat
10 - 100 cm	Sapric muck	Sapric muck
Soil hue/value/chroma	10YR 3/2	10YR 2/1

provided similar results to the scoring procedure in that sites with the lowest ranks (5-24) corresponded to sites with the lowest scores, and sites with the highest ranks (45-55) correspond to sites with the highest scores (Table 19). Principal components analysis (PCA) verified the classification scheme. All sites in a given resistance group were plotted in close proximity to each other except for site 26 (Figure 25). PCA results indicated that site 26 was physically more similar to I sites than H sites. However, I chose to leave site 26 in the H group because it met the criteria I had defined for high resistance sites.

The three forest resistance groups were fairly distinct from each other for all four classification variables. L forest sites had the lowest elevations above MSL, the smallest elevation differences above their adjacent seaward zones, the flattest slopes, and were predominately located on hydric soils (Figure 26). I sites had intermediate elevations above MSL, intermediate elevation differences above their adjacent zones, intermediate slopes, and were predominately located on nonhydric soils (Figure 26). H sites had the highest elevations above MSL, the largest elevation differences above their adjacent seaward zones, the steepest slopes, and were almost all located on nonhydric soils (Figure 26).

High marsh sites were also classified into three resistance groups: low (L), intermediate (I), and high (H) using the sum of scores for the five variables that describe high marsh resistance to state change to low marsh (Table 5). High marsh sites with total scores between 0-2 were classified as L resistance; high marsh sites with scores between 3-5 were classified as I resistance; sites with scores between 5-7 were classified as H

Table 15. Forest scores and ranks by resistance group: low (L), intermediate (I), and high (H).

Resistance group	Site ID	Soil Series Hydric = 0, Nonhydric = 1	SCORE	Elev. above MSL (m) 0-1.25=0, 1.25-1.40=1, >1.40=2	SCORE	RANK	Slope (F1:L2) <0.01 = 0, 0.01-0.02=1, >0.02=2	SCORE	RANK	Elev. above Seaward Zone (m) <0.15=0, 0.15-0.30=1, >0.30=2	SCORE	RANK	Total Score	Total Rank
L	BFF	NmA	0	1.16	0	3	0.0010	0	1	-0.01	0	1	0	5
	9	NmA	0	0.97	0	1	0.0016	0	3	0.10	0	3	0	7
	12JB	NmA	0	1.28	1	8	0.0013	0	2	0.14	0	5	1	15
	2	NmA	0	1.17	0	5	0.0054	0	5	0.18	1	8	1	18
	3	NmA	0	1.19	0	7	0.0026	0	4	0.29	1	11	1	22
	21B	BkA	1	1.17	0	6	0.0071	0	6	0.15	1	7	2	19
	11	NmA	0	1.38	1	10	0.0177	1	12	0.08	0	2	2	24
I	13H	MuA	1	1.43	2	13	0.0084	0	7	0.11	0	4	3	24
	12T	BoA	1	1.33	1	9	0.0348	2	17	0.14	0	6	4	32
	22	DrA	0	1.54	2	16	0.0110	1	8	0.26	1	9	4	33
	21	NmA	0	1.39	1	11	0.0146	1	10	0.38	2	15	4	36
	BSN	MuA	1	1.41	2	12	0.0146	1	9	0.29	1	12	5	33
	17	MuA	1	1.16	0	4	0.0290	2	16	0.32	2	13	5	33
	28	MoD	1	1.12	0	2	0.0423	2	18	0.34	2	14	5	34
	13	BoA	1	1.48	2	15	0.0152	1	11	0.28	1	10	5	36
H	26	DrA	0	1.45	2	14	0.0254	2	15	0.57	2	16	6	45
	27	MoD	1	1.70	2	18	0.0177	1	13	0.82	2	19	6	50
	5	BkA	1	1.55	2	17	0.0247	2	14	0.74	2	18	7	49
	8	BkA	1	1.74	2	19	0.0720	2	19	0.71	2	17	7	55

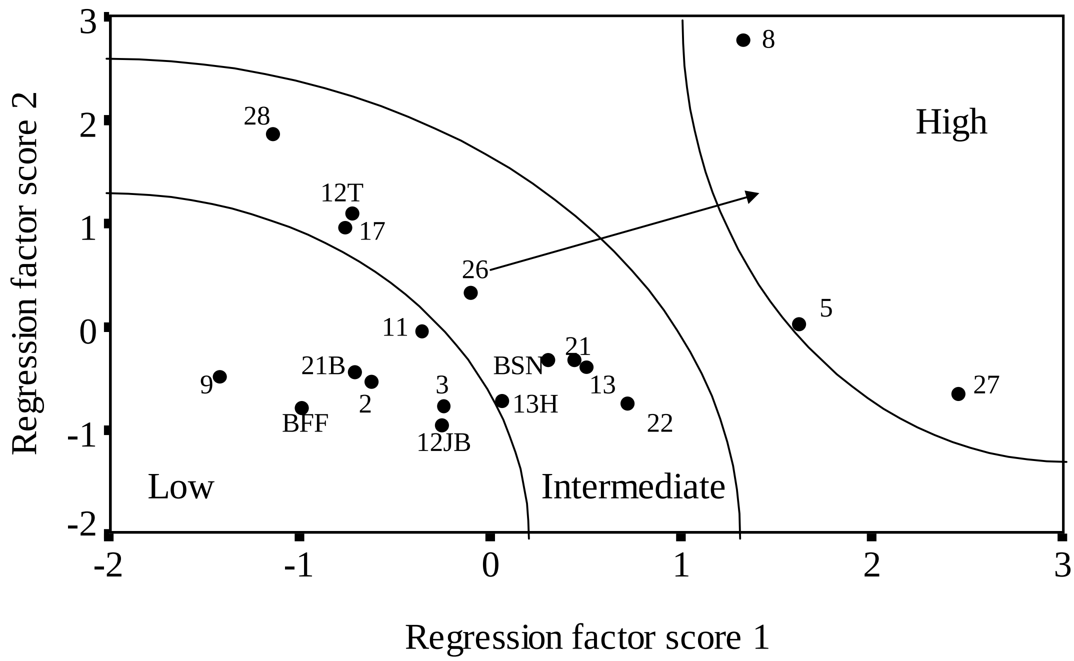


Figure 25. Ordination plot of forest sites using principal components analysis. Ordination represents similarity of sites based on three of the variables (elevation above MSL, slope between forest and low marsh, elevation above adjacent zone) used to classify the forest sites into resistance groups. Soil drainage type was not used because its values were not numerical. Points are labeled with their corresponding site number and resistance groups are outlined. Site 26 was the only site not grouped with its predefined resistance group.

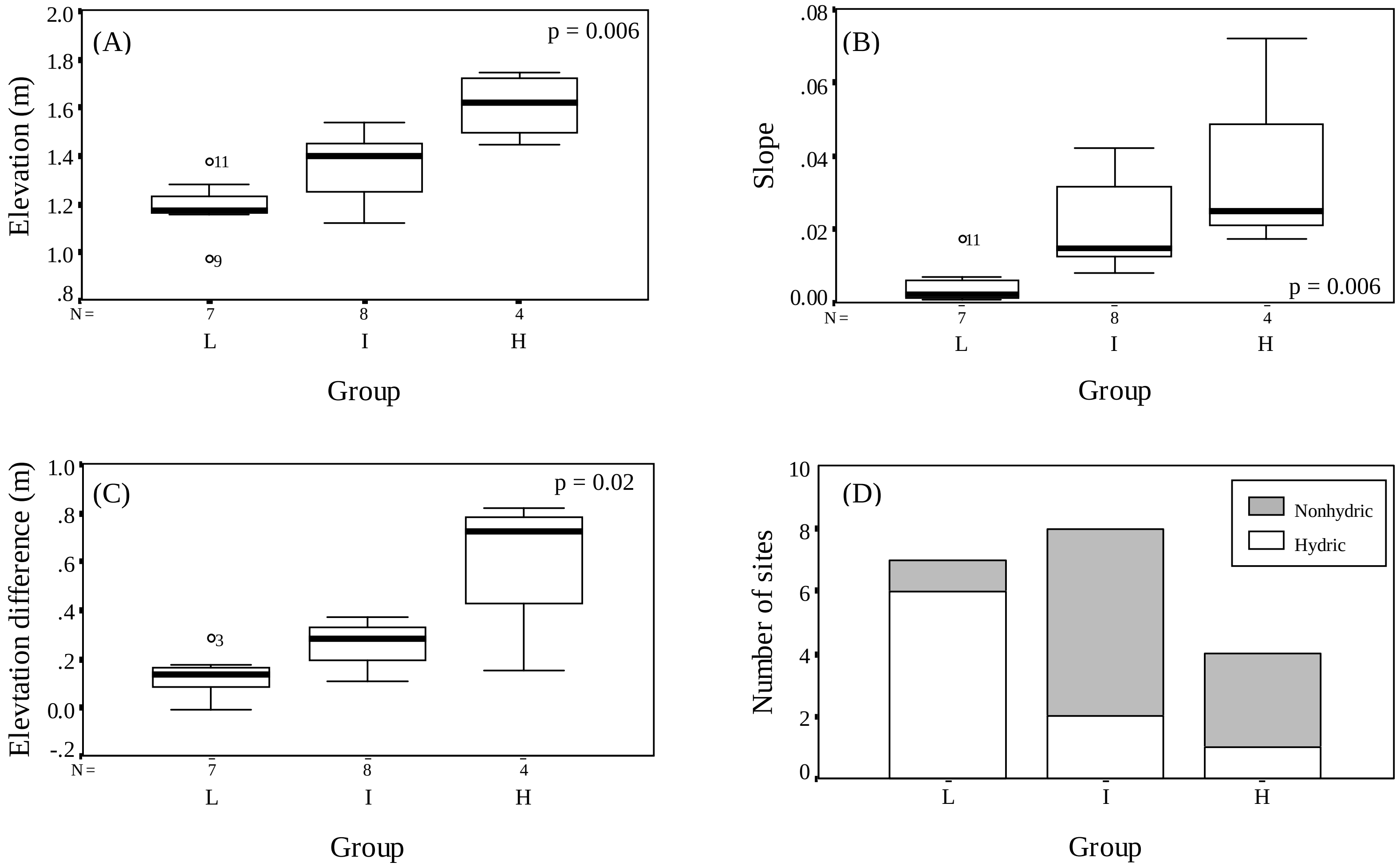


Figure 26. Variables (A) elevation above MSL, (B) slope between F1 and L2, (C) elevation of forest above adjacent seaward zone, and (D) soil type, used to classify forest sites into three resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17. P values were calculated using the Kruskal Wallis test, a nonparametric analysis of differences in means based on sample ranks.

resistance (Table 20). The ranking procedure provided similar results to the scoring procedure in that sites with the lowest total scores had the lowest total ranks (18-28) and sites with the highest total scores had the highest total ranks (48.0-55.5) (Table 20). I split the score of 5 between I and H resistance groups because there appeared to be a large difference in the total rank (Table 20) and ordination position (Figure 27) between the two sites (12JA and 28) with a score of 5. Ordination results verified the scoring procedure (Figure 27). Sites within a given resistance group were plotted closest to each other with exception for site 13 (Figure 27). According to PCA results site 13 is more similar to the sites in the I resistance group than those of the H resistance group. I chose to leave site 13 in the H resistance group because it met the criteria I had defined for high resistance sites. Site 18 was missing elevation above MSL data but its other variables were most similar to the L group's, so it was classified into the L group. I did not have loss on ignition data for site 12JA, but because its depth of the organic rich horizon was the same as site 13, it was assigned 12.2 %. Based on these procedures, seven high marsh sites were classified into the L group, six sites into the I group, and four sites into the H group (Table 20).

Although the three high marsh resistance groups were fairly distinct from each other, they were not distinct in all variables (Figure 28). L high marsh sites had the lowest elevation differences above the low marsh, whereas, I and H sites were similar in this variable (Figure 28A). L and I sites both had gradual slopes (<0.01), and H sites were generally between 0.03 - 0.04 (Figure 28B). L sites had the lowest elevations above MSL,

Table 20. High marsh scores and ranks by resistance group: low (L), intermediate (I), and high (H).

Resistance Group	Site ID	Elevation above MSL (m) 0-0.87 =0, >0.87 =1	SCORE	RANK	Slope of High Marsh (T1:L2) <0.01 =0, 0.01-0.02=1, >0.02=2	SCORE	RANK	Elev. above Low Marsh (m) 0-0.15=0, 0.15-0.3=1, >0.3 =2	SCORE	RANK	Depth of Organic Horizon (m) <0.1=2, 0.1-0.2=1, >0.2=0	SCORE	RANK	Surface Organic Matter (%) 0-20%=1, >20% = 0	SCORE	RANK	Total Score	Total Rank
L	27	0.83	0	2	0.0051	0	8	0.12	0	6	1.00	0	1	50.2	0	4	0	18.0
	26	0.85	0	6	0.0027	0	5	0.02	0	1	0.15	1	7	61.9	0	1	1	16.5
	11B	0.85	0	5	0.0091	0	10	0.19	1	12	0.45	0	3	59.5	0	2	1	28.5
	12JB	0.94	1	10	0.0012	0	3	0.05	0	2	0.15	1	8	47.6	0	5	2	20.5
	3	0.88	1	7	0.0011	0	2	0.18	1	10	0.79	0	2	24.6	0	8	2	21.5
	9	0.96	1	12	0.0013	0	4	0.25	1	14	0.35	0	4	54.3	0	3	2	29.5
	18	?			0.0128	1	13	0.06	0	3	0.20	1	6	42.0	0	6	2	28.0*
I	BFF	1.00	1	14	0.0009	0	1	0.19	1	11	0.10	1	10	33.7	0	7	3	32.5
	2	0.85	0	4	0.0042	0	6	0.31	2	15	0.12	1	9	21.7	0	9	3	36.5
	21B	0.93	1	9	0.0049	0	7	0.13	0	8	0.00	2	16	8.6	1	14	4	42.5
	13H	1.02	1	15	0.0067	0	9	0.08	0	4	0.00	2	16	9.3	1	13	4	43.0
	BSN	0.94	1	11	0.0124	1	12	0.14	0	9	0.10	1	11	15.1	1	11	4	43.0
	12JA	1.06	1	16	0.0114	1	11	0.11	0	5	0.05	2	12.5	?	1	12	5	42.5*
H	28	0.79	0	1	0.0423	2	17	0.13	0	7	0.00	2	16	5.4	1	15	5	48.0
	22	0.91	1	8	0.0325	2	16	0.37	2	16	0.30	0	5	15.8	1	10	6	46.0
	13	0.99	1	13	0.0143	1	14	0.20	1	13	0.05	2	12.5	12.2	1	12	6	52.0
	17	0.84	0	3	0.029	2	15	0.43	2	17	0.02	2	14	2.5	1	16	7	55.5

* Site 18 was missing elevation above MSL data. It was classified into the L resistance group because its other characteristics were most similar to those of the L group. Site 12JA was missing loss on ignition data. However, because its organic rich horizon depth was the same as site 13, its loss on ignition score and rank were assigned to be the same as site 13's.

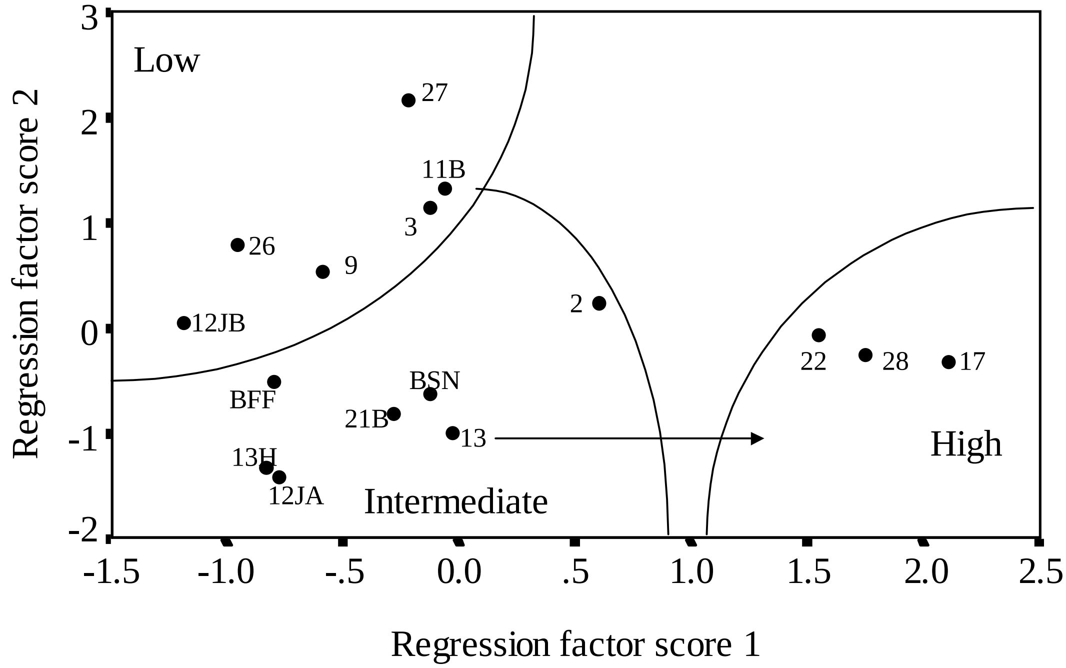


Figure 27. Ordination plot of high marsh sites using principal components analysis. Ordination represents similarity of sites based on the five variables (elevation above adjacent zone, high marsh slope, depth of organic rich horizon, percent organic matter, elevation above MSL) used to classify the high marsh sites into resistance groups. Points are labeled with their corresponding site number and resistance groups are outlined. Site 13 was the only site not grouped with its predefined resistance group.

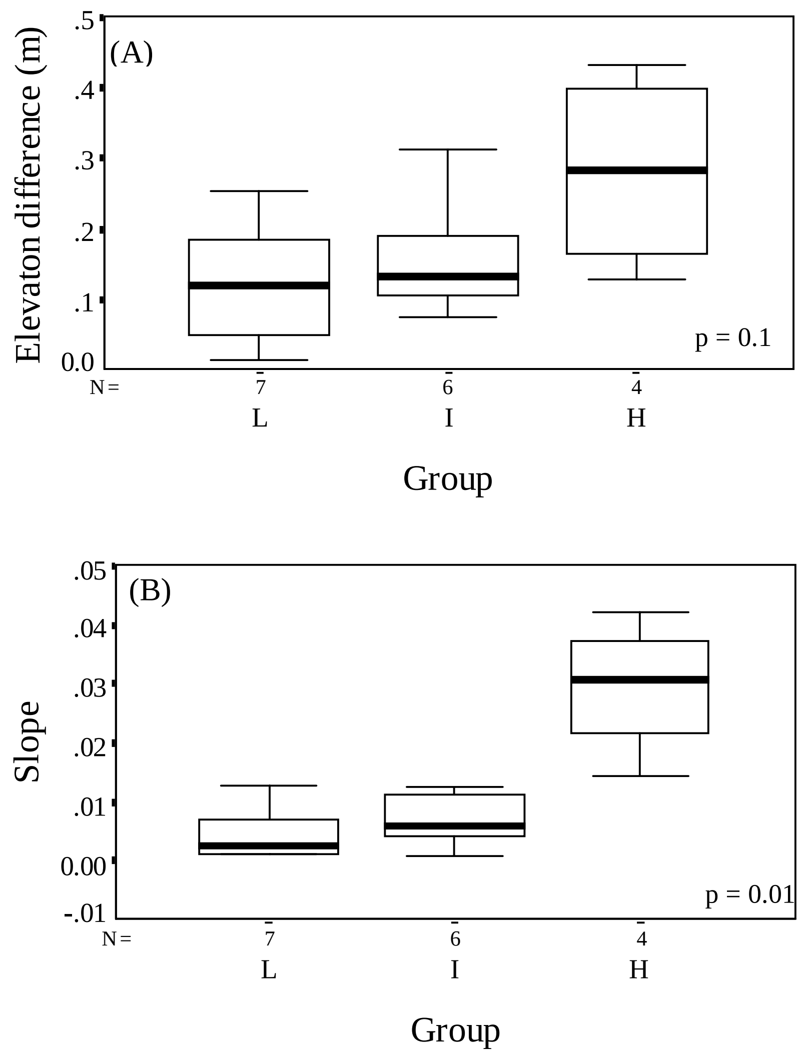
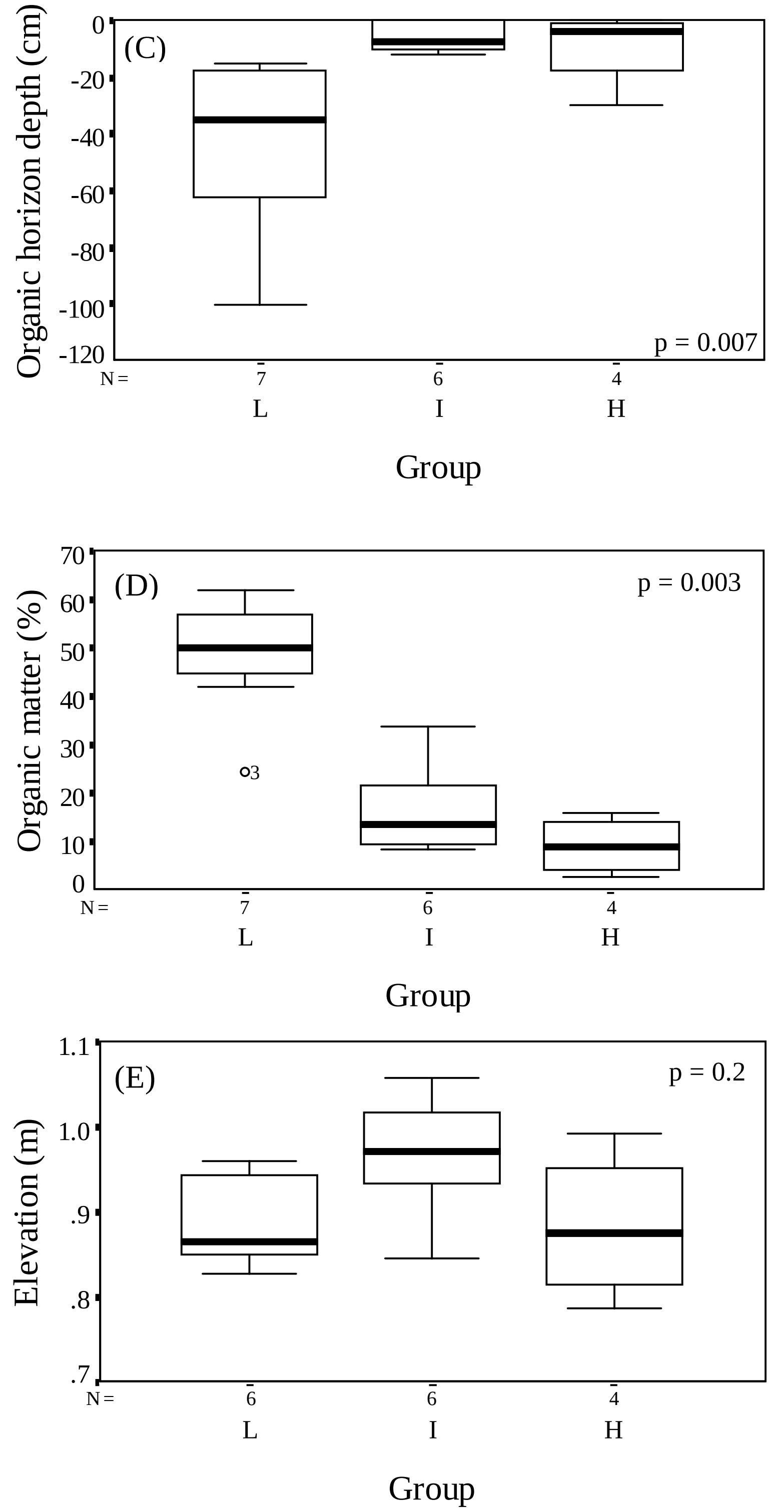


Figure 28. Variables (A) elevation of high marsh above low marsh, (B) slope of high marsh, (C) depth of organic rich zone from soil surface, (D) percent organic matter (0-10 cm), and (E) elevation of high marsh above MSL, used to classify high marsh sites into three resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

Figure 28. Continued.



and I and H sites were basically similar in elevation (Figure 28E). L sites had the thickest O horizons (Figure 28C), and the highest percent organic matter in their soil surface (Figure 28D). I and H sites were similar in terms of organic matter characteristics; they both had very thin O horizons and little organic matter in their soil surface.

Initially, distance to closest tidal source from the seaward side of the zone was used in the classification procedure for these sites. However, analysis revealed there was considerable overlap between the three resistance groups for both zones classified (forest and high marsh) and for transition sites (Figure 29). Therefore, it was removed from the classification procedure.

4.4 Resistance Group Comparison

Two physical components of vegetation structure varied by forest resistance groups, but not significantly at the 0.05 level (Figure 30). Vegetated ground cover and shrub density were inversely related ($r = -0.75$, $p = 0.002$). Forest sites with the highest resistance had the lowest shrub densities and the most herbaceous cover, whereas forests with the lowest resistance had the highest shrub densities and least herbaceous cover. Tree density, basal area and canopy cover did not differ among the three resistance groups.

Ground cover species richness did not vary by resistance group, but percent vegetated ground cover decreased with decreasing resistance (Table 21). Woody species

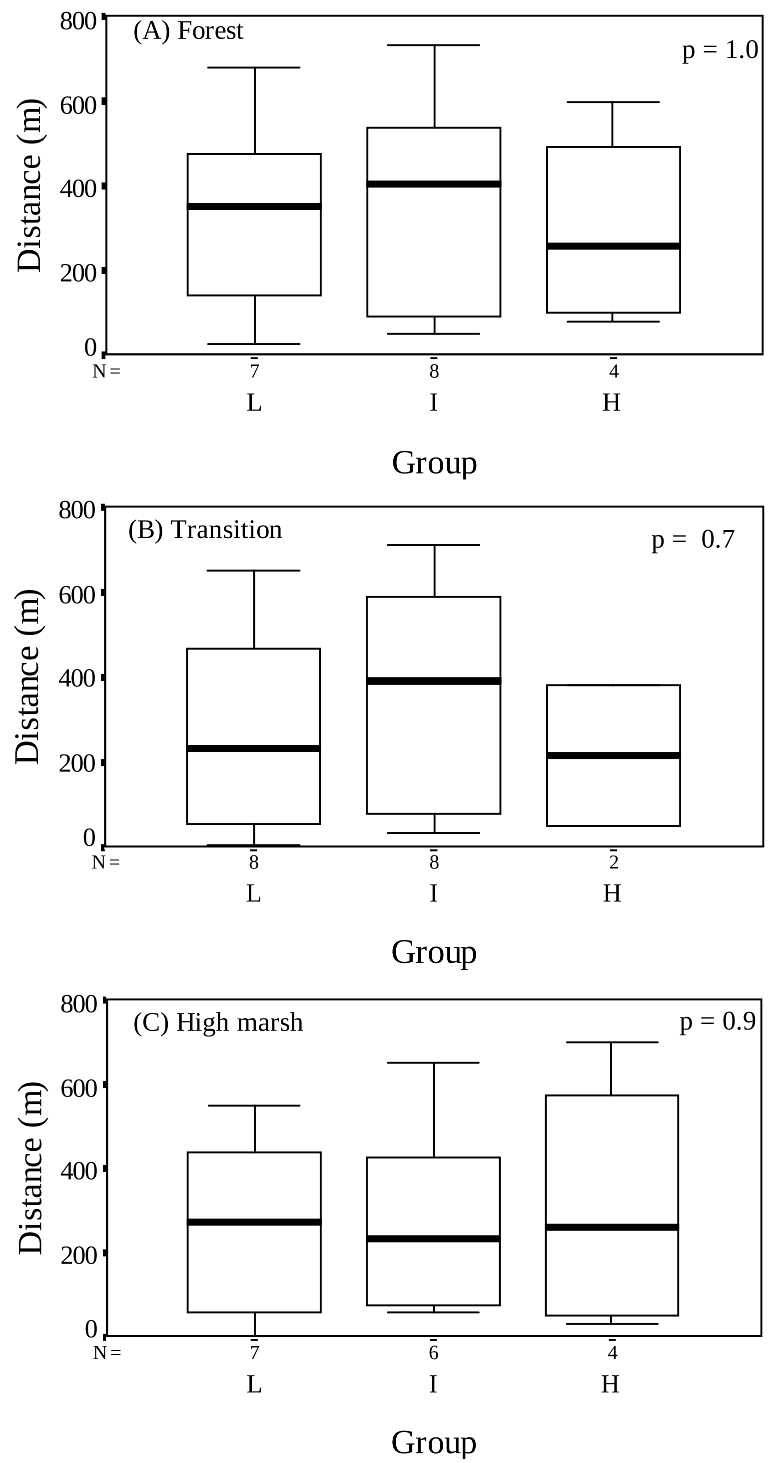


Figure 29. Boxplots showing distance from the nearest tidal source for the (A) forest, (B) transition, and (C) high marsh grouped by resistance groups: low (L), intermediate (I), high (H). Transition sites are grouped according to their forest's resistance. Boxplot components are described in Figure 17.

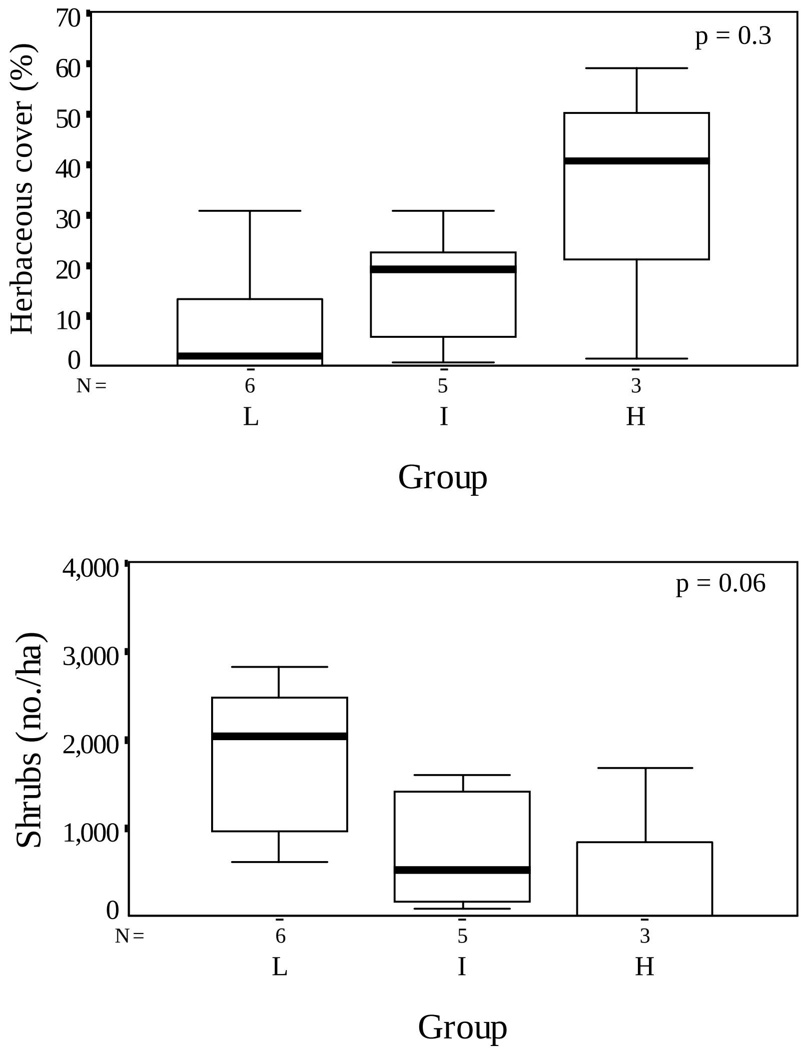


Figure 30. Boxplots showing physical vegetation structure components for the three forest resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

Figure 30. Continued.

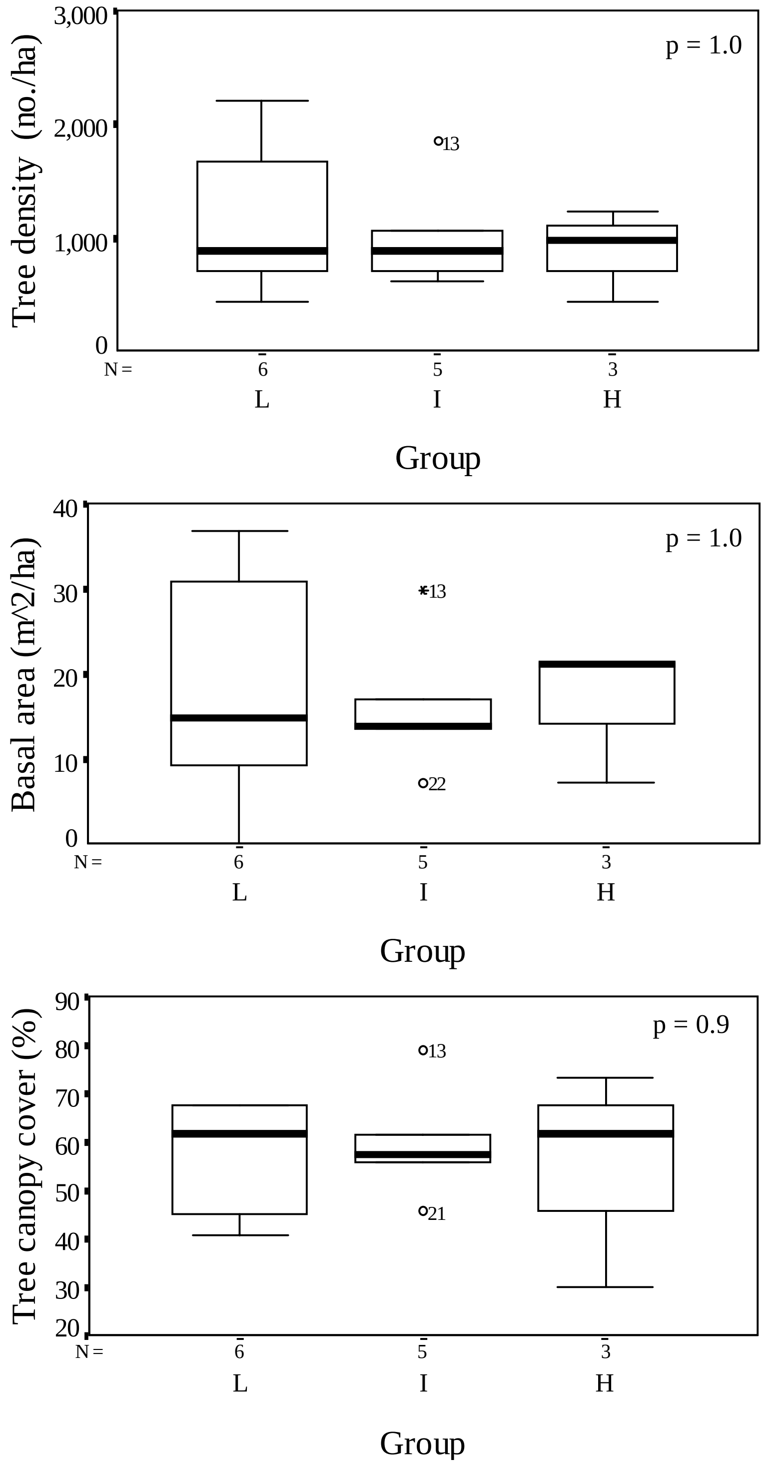


Table 21. Relative % ground cover (0-1m) and woody species IV's for forest resistance groups: low (L), intermediate (I), and high (H). Relative cover was calculated same as Table 10 and IV's were calculated same as Table 11. Values <1 are not reported.

	Ground Cover (%)				Importance Value		
Cover Type or Species	**L**	**I**	**H**		**L**	**I**	**H**
n=	**18**	**15**	**9**		**6**	**5**	**3**
Myrica cerifera	6	6			20	6	8
Juniperus virginiana		5	4		24	23	12
Pinus taeda	3		2		38	33	23
Prunus serotina					2	6	1
Nyssa sylvatica					7		3
Baccharis halimifolia						2	
Ilex opaca						6	3
Celtis occidentalis						19	32
Liquidambar styraciflua		2				4	8
Aralia spinosa			2				5
Lirodendron tulipifera							5
Magnolia virginiana							1
Pinus serotina	1						
Persea borbonia	2						
Panicum virgatum	2						
unidentified gramminoid	5						
Rhus radicans	1	7	5				
Iva frutescens		1					
Limonium carolinium		2					
Atriplex patula		1					
Bignonia capreolata		4	3				
Asclepias incarnata			4				
Smilax bona-nox			10				
Erechtites hieracifolia			9				
Bare ground			4				
Crab burrow	7						
Woody debris	15	14					
Litter	59	57	52				
Wrack			3				
Vegetated Total	**19**	**29**	**41**				
Unvegetated Total	**81**	**71**	**55**				
Hardwood Total					**9**	**37**	**58**
Grand Total	**100**	**100**	**100**		**92**	**100**	**100**

richness was slightly higher for H forest sites and hardwood species importance increased with increasing resistance. Hardwood species IVs were 9 for L sites, 35 for I sites, and 58 for H sites (Table 21). *M. cerifera* and *P. taeda* decreased in importance with increasing resistance, and *C. occidentalis* increased in importance with increasing resistance (Table 21). L sites were dominated by *P. taeda, M. cerifera*, and *J. virginiana*. I sites were dominated by *P. taeda* and *J. virginiana* with *M. cerifera and C. occidentalis* next in importance. H sites were dominated by *P. taeda* and *C. occidentalis* but also had a strong mix of hardwoods and *J. virginiana*. There were no significant differences between the three groups for dead tree or stump densities; however, the sites with the highest densities for both components were in the L group (Figure 31).

The L forest group had significantly higher salinities ($p = 0.038$) compared with the I and H groups, and significantly higher soil organic matter ($p = 0.01$) compared with the H group (Figure 32). Although a significant difference was not present, depth of the organic rich horizon was generally deeper for L sites (Figure 32).

All L forest sites, 80 % of I forest sites, and 50 % of H forest sites had transition zones between their forest and marsh. I forest-marsh transitions occurred at the highest elevations and H transitions occurred at the lowest elevations, where present (Figure 33). L transition sites had a wide range in elevation above MSL. There were no significant differences between the three groups in terms of transition zone elevation above adjacent seaward zone. H transitions, where present, had much steeper slopes compared with the other two groups ($p = 0.03$), and were extremely narrow in width (i.e.$\leq$6 m). Transitions

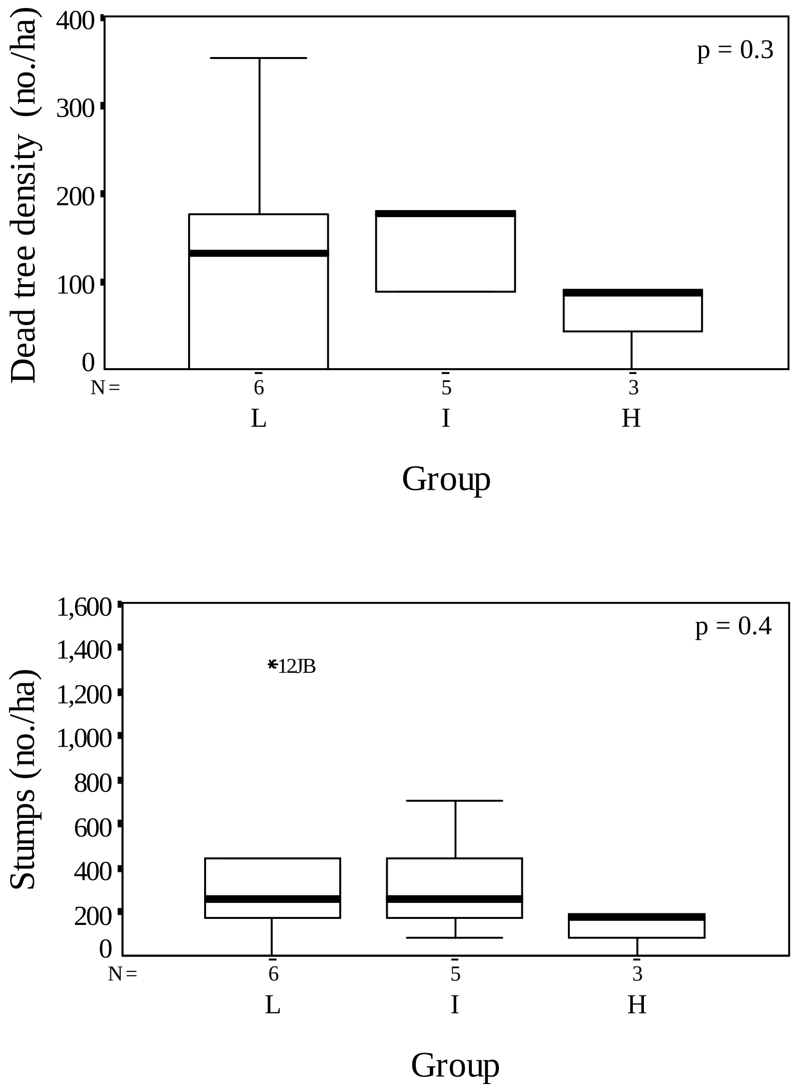


Figure 31. Boxplots showing dead vegetation components for forest resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

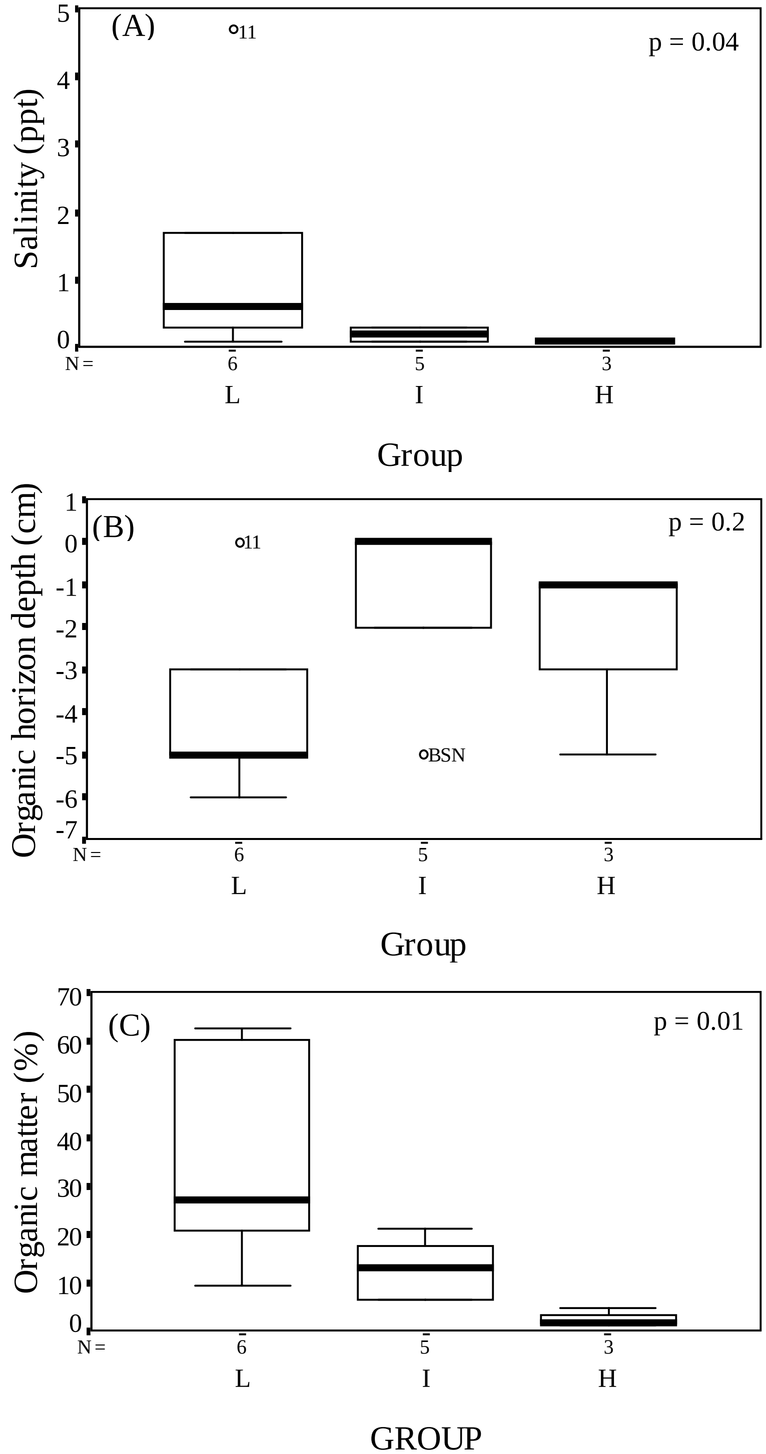


Figure 32. Boxplots showing soil characteristics (A) salinity (0-10 cm), (B) depth of organic rich soil beneath ground surface, (C) percent organic matter (0-10 cm) for forest resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

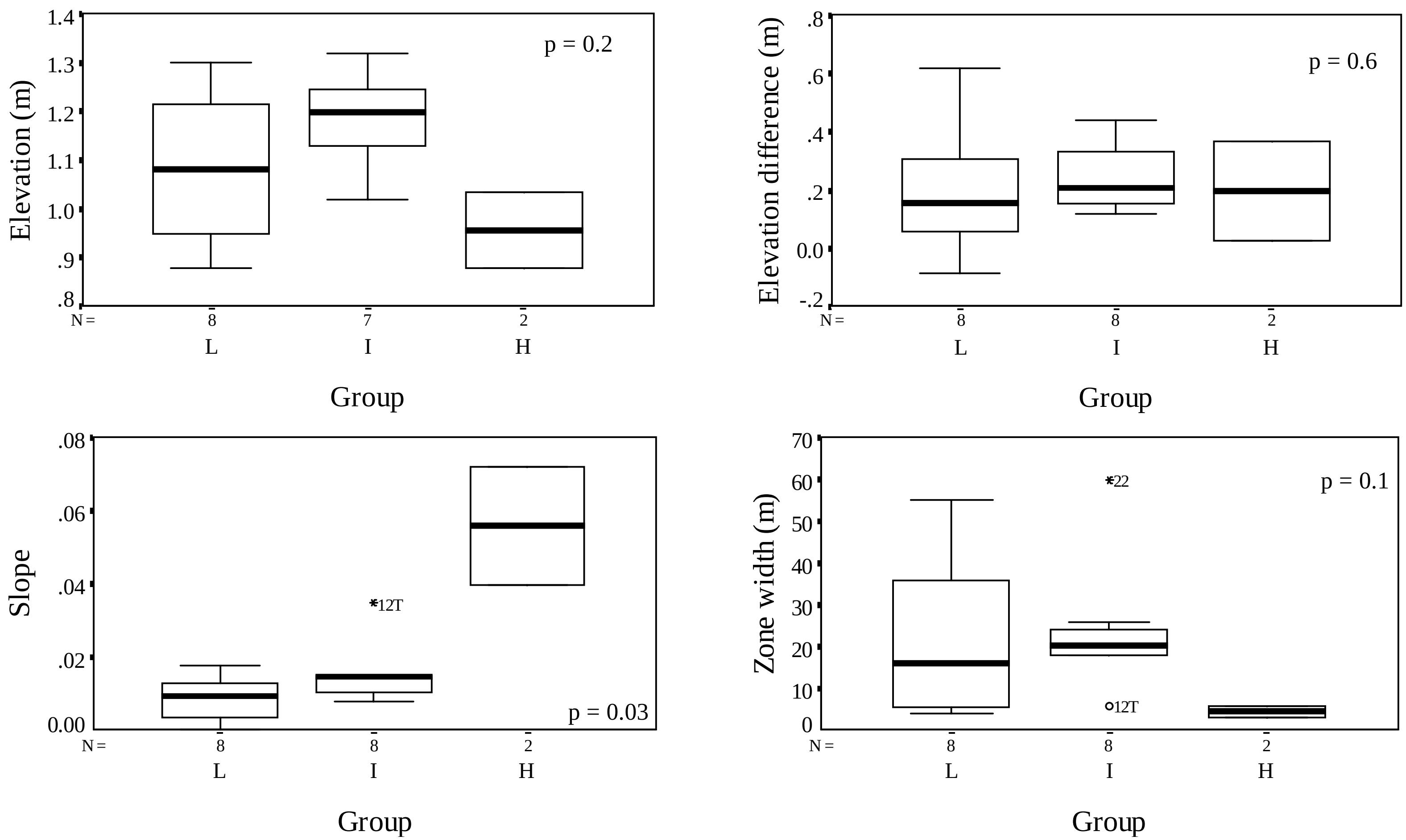


Figure 33. Physical characteristics of transition sites grouped by their forest resistance groups: low (L), intermediate (I), and high (H). The graph displaying elevation difference refers to the elevation difference between the average elevation of the transition zone and the average elevation of the high marsh or L2 where the high marsh is absent. Boxplot components are described in Figure 17.

forming seaward of L and I forests varied in width from very narrow (< 6m) to very wide (>50 m).

Physical components of the vegetation structure showed no significant differences between the three transition groups (Figure 34). There were a few more trees in the L transitions and subsequently more basal area and canopy cover, compared with those transitions forming seaward of I and H forests. Tree canopy cover was present in some sites lacking trees due to shading from trees in the adjacent forest zone. Percent herbaceous cover did not correlate with canopy cover, tree density, or shrub density in the transition zone.

Transition zones forming seaward of L forests differed from the others in terms of species composition (Table 22). L transitions had the lowest *S. patens* cover, and the highest percent cover of less salt tolerant species (19 %) compared with the other transition groups (I, 9 %; H,13 %). Furthermore, L transitions had the lowest vegetated to unvegetated ground cover ratio, and the most wrack. I forest transitions were most different from L transitions. I sites had the lowest cover of less salt tolerant species and the highest vegetated to unvegetated ground cover ratio. H forest transitions had a combination of both I and L transition characteristics. For both woody species IVs and ground cover composition, L and I transitions were most different, and H transitions showed a combination of the two extremes. L forest transition sites were dominated by species that were fairly salt intolerant (IV = 69). More notably, L transitions almost always lacked or had very little of the shrub *I. frutescens* which is often characteristic of transition zones. Only one L transition site, 21B, was dominated by *I. frutescens* and this

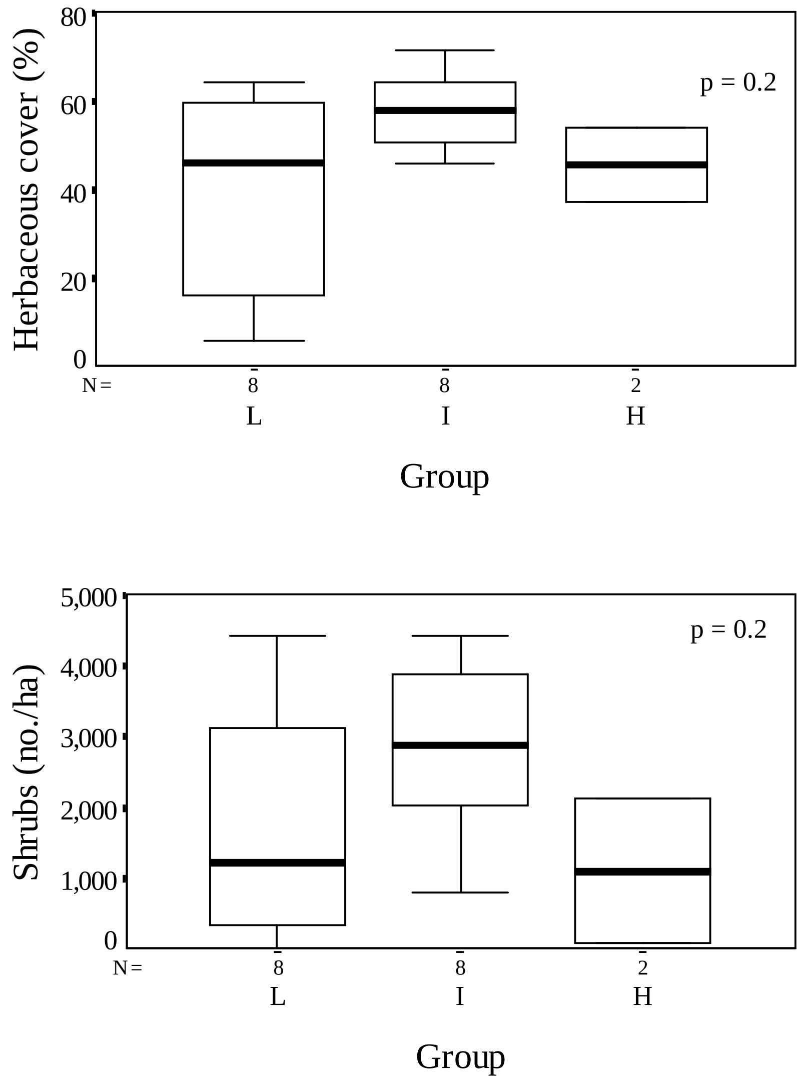


Figure 34. Boxplots showing vegetation structure components for transition sites grouped by their forest resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

Figure 34. Continued.

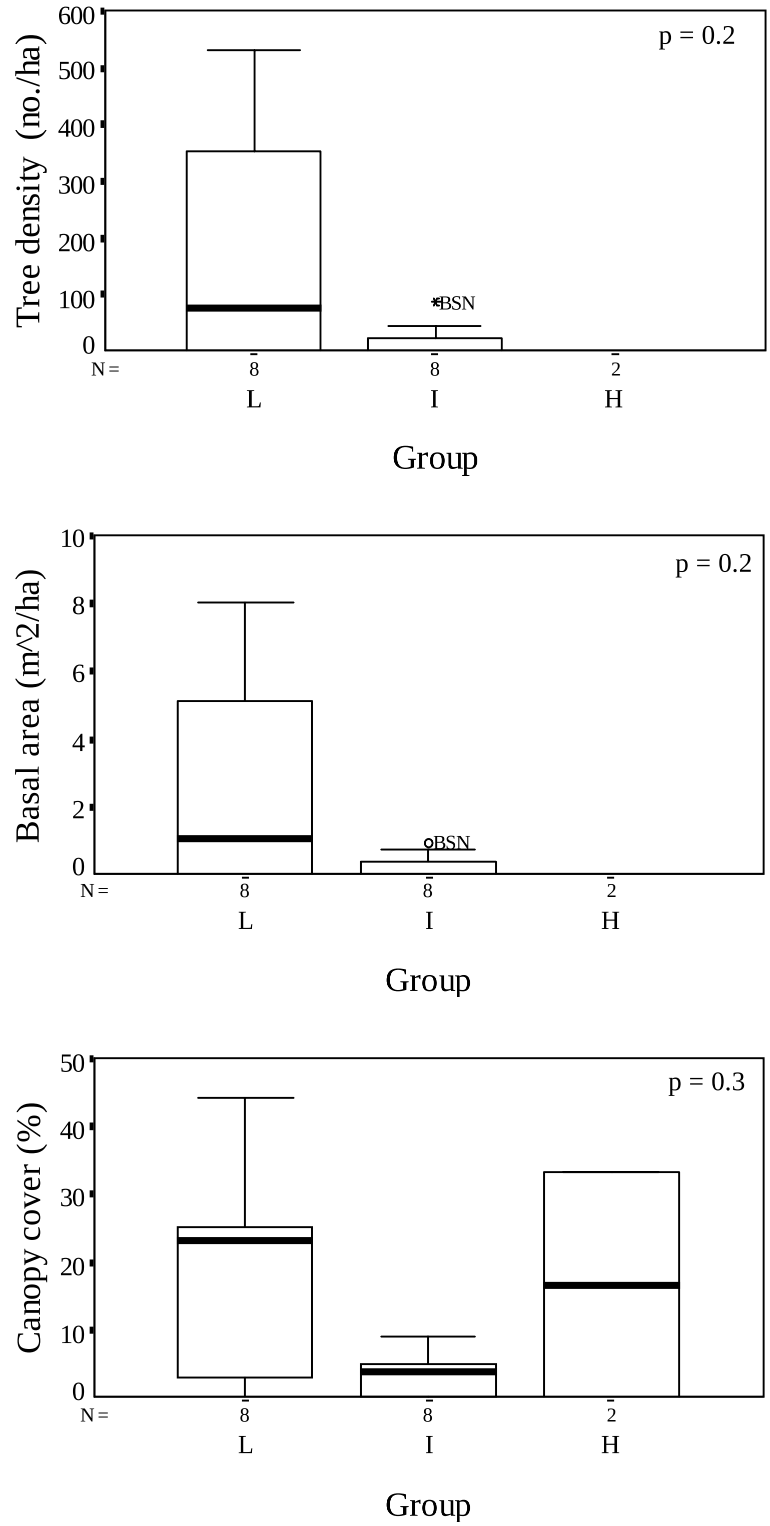


Table 22. Relative percent ground cover (0-1m) and woody species IVs for transition

sites grouped by forest resistance groups: low (L), intermediate (I), and high (H). Relative cover was calculated same as Table 10 and IVs were calculated same as Table 11. Values <1% are not reported. Less salt tolerant species (LST) are indicated with an *.

Cover Type or Species	**Ground Cover (%)**				**Importance Value**		
	L	**I**	**H**		**L**	**I**	**H**
n=	**39**	**48**	**6**		**13**	**16**	**2**
*Pinus taeda**	2	1			11	2	
*Juniperus virginiana**	1				31	7	4
*Myrica cerifera**	5		10		27		21
Iva frutescens	10	22	12		21	73	54
Baccharis halimifolia		5			10	19	21
Typha sp.*	2						
unidentified graminoid*	1	1					
Spartina patens	14	29	29				
Distichlis spicata	7	12	2				
*Panicum virgatum**	7	5	2				
*Setaria viridis**	1	1					
Juncus roemerianus	7		5				
Spartina alterniflora		1	7				
Juncus gerardi		7					
Limonium carolinium		1					
*Asclepias incarnata**		1					
Stump	1						
Dead tree	1	1					
Dead shrub	2	1					
Woody debris	4	1					
Wrack	11	1					
Litter	16	5	19				
Bare ground	8	4	14				
Pothole		2					
Vegetated Total	**58**	**85**	**76**				
Unvegetated Total	**42**	**15**	**33**				
LST species (*) Total	**19**	**9**	**13**		**69**	**9**	**25**
Grand Total	**100**	**100**	**100**		**100**	**100**	**100**

site was unusual in that it was the only L forest site with nonhydric soils. Transitions forming seaward of L forests were dominated by *M. cerifera* and *J. virginiana* in the shrub stratum, but also had *P. taeda* and *B. halimifolia*. Transitions forming seaward of I forests were all dominated by *I. frutescens*. Most I transitions also had a prevalence of *B. halimifolia* and/or *J. virginiana*. Species composition was more variable in H transitions; *I. frutescens* dominated one of the H forest transition sites while *B. halimifolia* and *M. cerifera* dominated the other. However, because the sample size for H transitions is so low (n = 2) it is hard to draw conclusions about this group.

Dead shrub densities had a similar pattern for both size classes (<1 m and >1 m). L and H transitions had no dead shrubs and I transitions ranged between 0-400 stems/ha for both size classes with exception for one outlier (Figure 35). Dead shrub densities of both size classes were inversely related to salinity (shrubs <1 m $r = -0.68$, $p = 0.003$; shrubs >1 m $r = -0.67$, $p = 0.004$). In general, dead tree density did not differ between the groups, although site 12JA, a small island, had an unusually high dead tree density 1,400 stems/ha). Stump density did not significantly differ between the three transition groups. Neither dead tree nor stump density were correlated with salinity.

Overall, soil characteristics did not significantly vary between the three transition groups (Figure 36). However, forest-marsh transitions with the highest salinities or deepest O horizons occurred next to I forests.

High marsh sites differed in several soil and physical factors, not used in the classification scheme, by group. Salinity decreased with increasing resistance to regular brackish water flooding and drainage potential (Figure 37). Most L high marsh sites

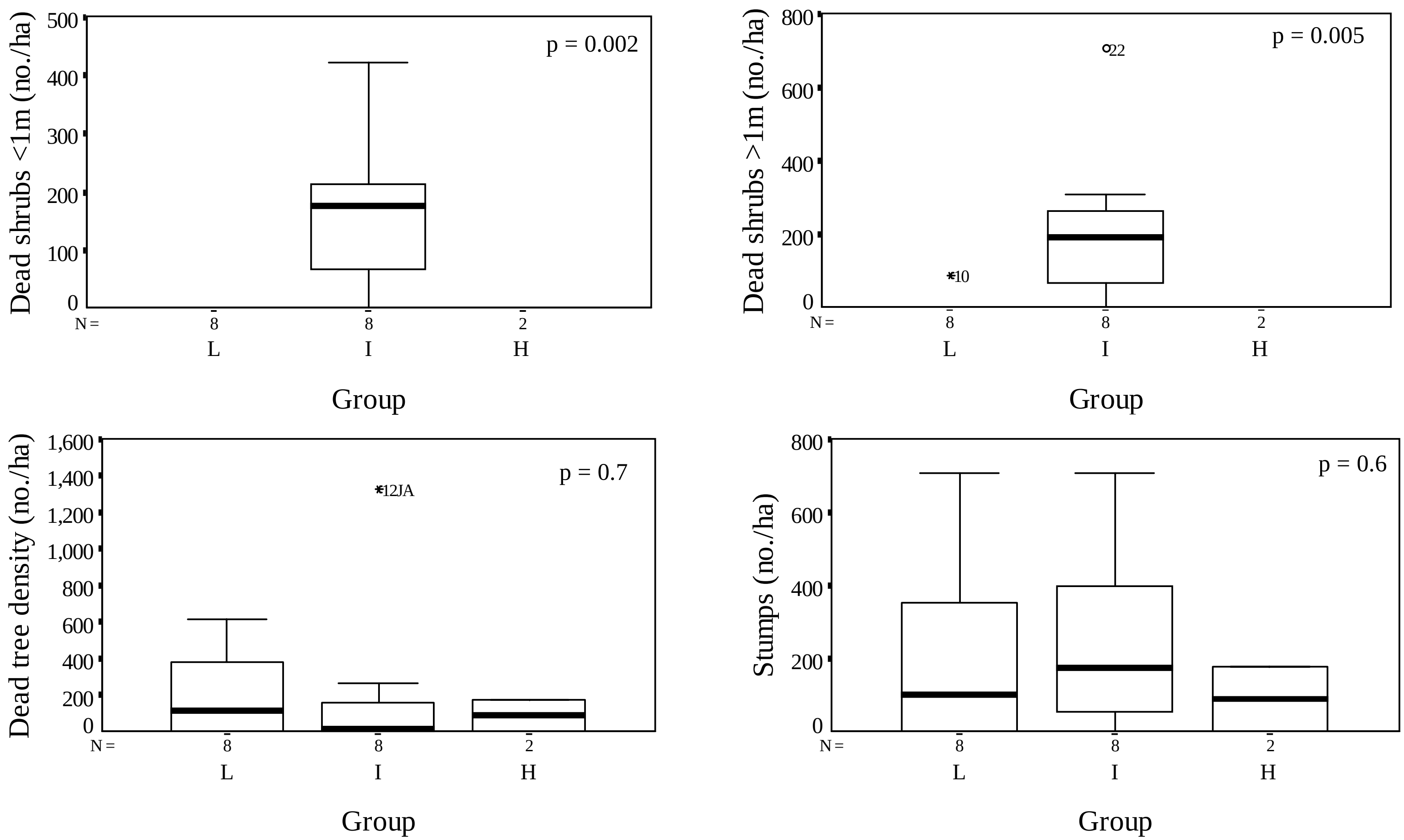


Figure 35. Dead vegetation components for transition sites grouped by their forest resistance groups (low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

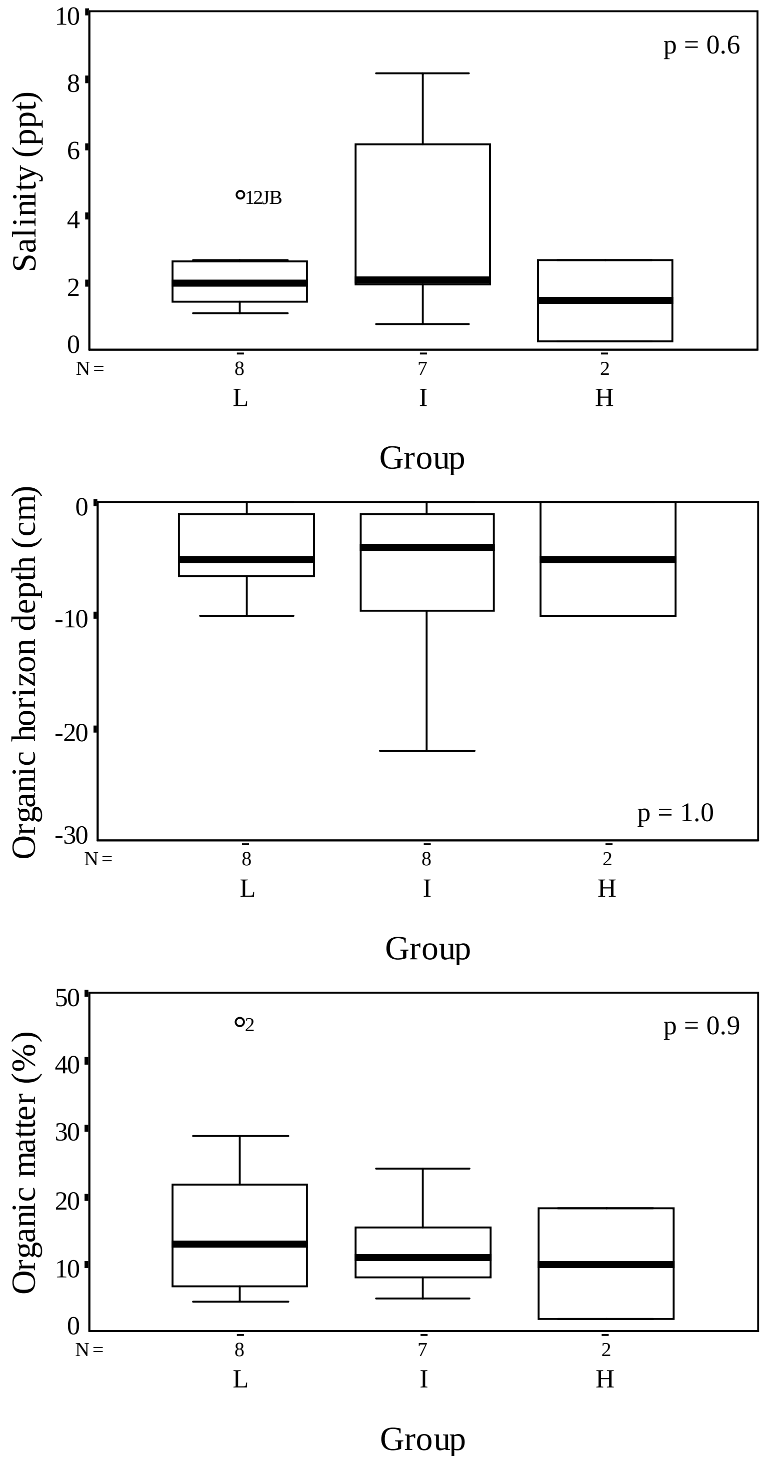


Figure 36. Boxplots showing soil characteristics (A) soil salinity (0-10 cm), (B) depth of organic rich horizon from ground surface, and (C) percent organic matter (0-10 cm) of transition sites grouped by their forest resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

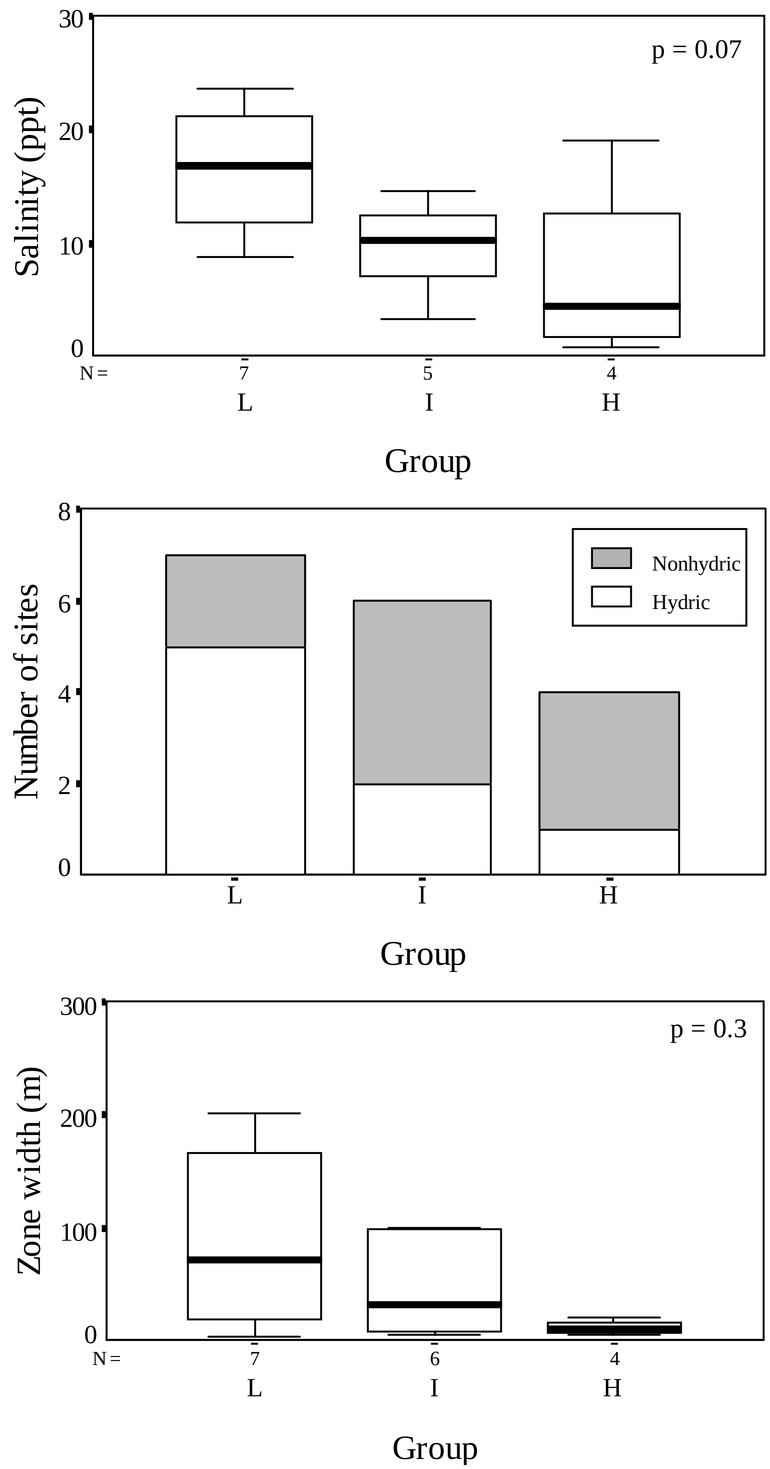


Figure 37. Boxplots showing physical characteristics, not used in the classification, of high marsh sites grouped by resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

formed seaward of hydric soils, whereas most I and H sites formed seaward of nonhydric soils. L and I sites generally had the widest high marsh zones whereas H sites had very narrow zone widths.

There were no significant trends between the three high marsh resistance groups in physical components of their vegetation structure (Figure 38). However, L high marsh sites usually lacked or had very few shrubs. Shrub density was inversely related to salinity ($r = -0.51$, $p = 0.045$) and percent herbaceous cover ($r = -0.65$, $p = 0.005$). The ratio of vegetated to unvegetated ground cover was similar for the three high marsh resistance groups (Table 23). I high marsh sites had a much lower percent cover of *Spartina patens* than the other two groups and had the most *J. roemarianus* and *D. spicata* cover. *Iva frutescens* had the lowest percent ground cover in L high marsh sites. *Iva frutescens* was the most important woody plant for all high marsh groups. *B. halimifolia* was also present in all groups.

L and H high marsh groups were similar in that they both commonly lacked dead short shrubs (<1 m), dead trees, and stumps (Figure 39). A few sites in the L group had dead tall shrubs (>1 m) but H sites had none. I high marsh sites had the most dead short shrubs <1 m, dead trees, and stumps. Site 12JA, the small island, had a high dead tall shrub (>1 m) density.

4.5 Resistance Group Map and Field Indicators

Two L forests lacked high marsh, four had L high marsh states, and three had I high marsh states (Table 24). Both sites (10,11) lacking high marsh occurred on wetland

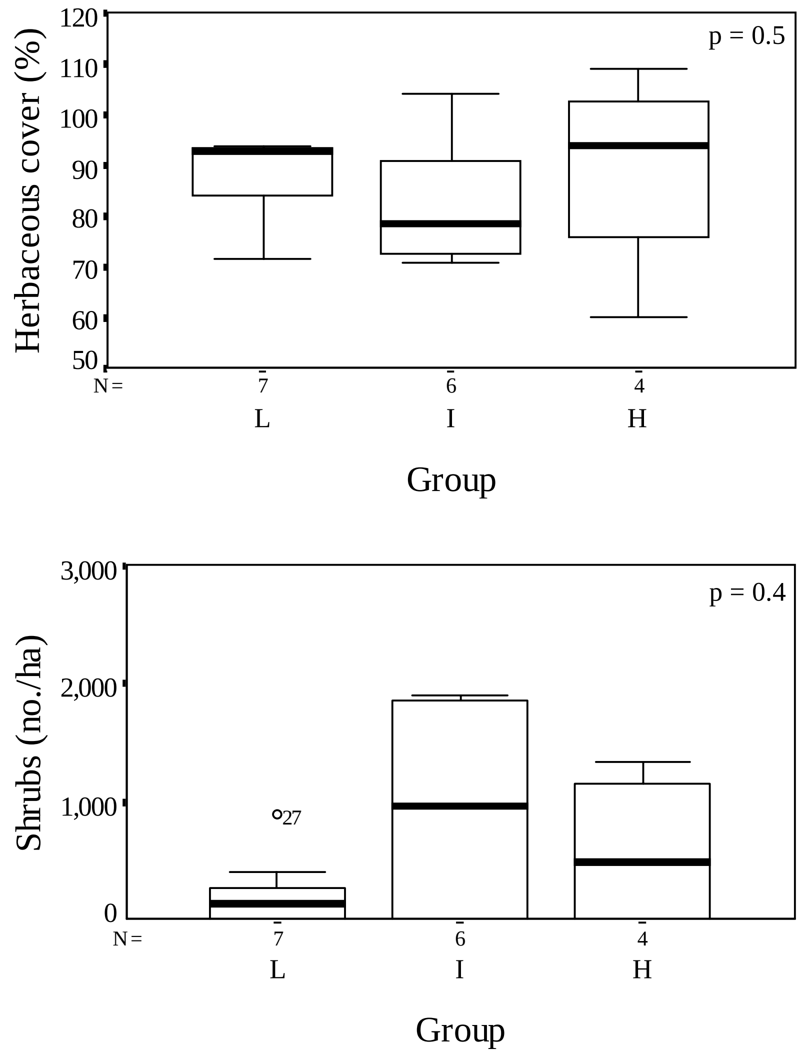


Figure 38. Boxplots showing physical vegetation structure components for high marsh resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

Table 23. Relative percent ground cover (0-1m) and woody species IVs for high marsh sites grouped by their resistance groups: low (L), intermediate (I), and high (H). Relative cover was calculated same as Table 10 and IVs were calculated same as Table 11. Values <1% are not reported.

	Ground Cover (%)			Importance Value		
Cover Type or Species	**L**	**I**	**H**	**L**	**I**	**H**
n=	**51**	**36**	**15**	**17**	**12**	**5**
Iva frutescens	2	7	9	30	50	47
Baccharis halimifolia		1		2	3	3
Spartina patens	47	21	53			
Distichlis spicata	23	38	21			
Limonium carolinium	1	1	2			
Juncus roemerianus	7	19				
Spartina alterniflora	4		1			
Juncus gerardi	7		3			
Setaria viridis			3			
Atriplex patula			1			
Borrichia frutescens			2			
Dead shrub	1					
Pothole	4	3				
Bare ground	2	6	3			
Wrack	3	2	2			
Vegetated Total	**91**	**88**	**95**			
Unvegetated Total	**9**	**12**	**5**			
Grand Total	**100**	**100**	**100**	**32**	**53**	**50**

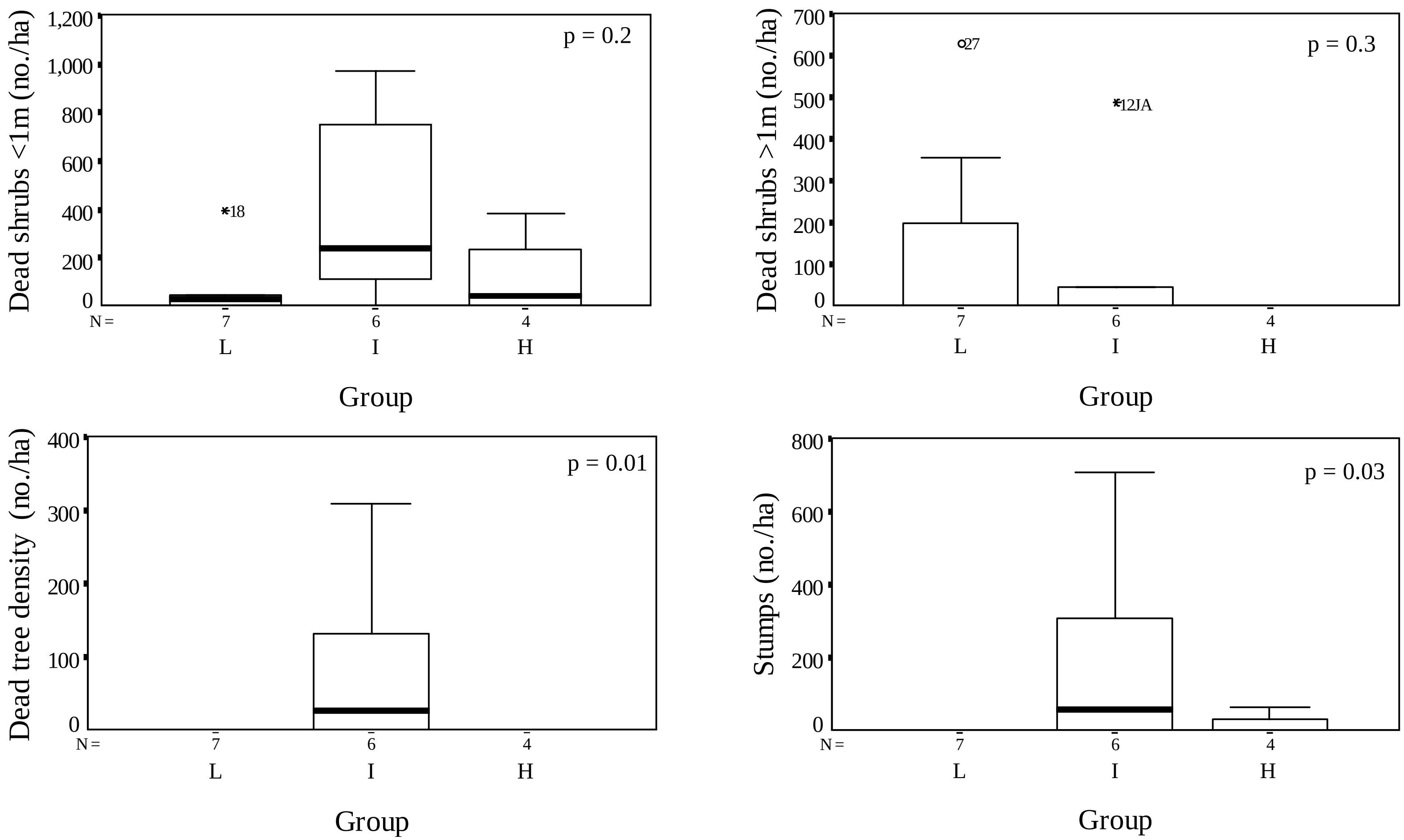


Figure 39. Boxplots showing dead vegetation components for high marsh resistance groups: low (L), intermediate (I), and high (H). Boxplot components are described in Figure 17.

Table 24. Field sites listed with their respective zones and zone widths. Forest and high marsh zones are listed by resistance group (low (L), intermediate (I), high (H)) or absent (-), and ground water seep zones are listed as present (+) or absent (-).

Site	Forest Resistance Group	Transition Zone Width (m)	High Marsh Resistance Group	High Marsh Zone Width (m)	Ground-Water Seep
10	L	55	-	0	-
11	L	20	-	0	-
3	L	4	L	176	-
9	L	4	L	157	-
12JB	L	42	L	202	-
11B	L	8	L	72	-
2	L	7	I	100	-
BFF	L	30	I	99	-
21B	L	12	I	33	-
12T	I	6	-	0	-
21	I	22	-	0	-
18	I	18	L	4	-
12JA	I	26	I	6	-
BSN	I	21	I	8	-
13H	I	18	I	32	-
13	I	20	H	13.5	-
22	I	60	H	8	-
17	I	0	H	20	-
28	I	0	H	6	-
5	H	0	-	0	+
8	H	3	-	0	-
26	H	6	L	6	-
27	H	0	L	33	+

islands or necks (Table 25). Regardless of resistance category to which a given high marsh belonged, when occurring next to L forests most were very wide (i.e. >70 m). The only exception was site 21B which was unique to the L forest group because its forest soil type was nonhydric (Table 25). Two I forest sites lacked high marsh, one had a high marsh in the low resistance category, three had I high marsh states, and four had H high marsh states. I forests tended to have high marsh widths that ranged from narrow (4 m) to somewhat wide (30 m). Two H forest sites lacked high marsh and the other two had low resistance high marsh states that varied in width (6 m and 33 m). One H forest site with high marsh and one without high marsh had groundwater seeps between forest and marsh. Both sites with a groundwater seep lacked a transition zone; the two without groundwater seeps had transitions but both very narrow (3 m and 6 m) (Table 24).

It was possible to identify all L forest sites using soil survey and USGS topographic maps by subdividing L forests into four subgroups (L_a, L_b, L_c, L_d) (Figure 40). L_a sites occurred on island or neck landforms with hydric forest soils (Table 25). L_b sites occurred on interfluve landforms that had hydric forest soils for extensive widths (i.e. $\geq$50 m) and/or the hydric Magotha (MaA) series (i.e. the soil series that high marsh and transition occurred on) for fairly extensive widths (i.e. $\geq$50 m). Widths were measured perpendicular to the estuarine boundary and scarp. L_c sites occurred on valley landforms and had hydric forest soils. L_d sites occurred on interfluve landforms with nonhydric forest soils and some MaA. The key feature of the L_d site was that it had a very wide (700 m) distance between the 1.5-3.0 m contours.

Table 25. Map characteristics for each field site grouped by their subdivided forest resistance group. The first letter of the forest resistance group designates low (L) intermediate (I) or high (H) resistance and the second letter represents the subclass. Both Magotha soil series and the elevation interval (1.5 - 3.0 m) widths were measured perpendicular to the estuarine boundary and scarp. Most necks and islands lacked elevations at 3.0 m and are shown as (-) for this variable. Site 13 also lacked this elevation because it has been drowned almost to the point of becoming a neck. Sites lacking hydric soils adjacent to their marsh are given (-) for the hydric soil width variable.

Forest Resistance Group	**Site**	**Forest Soil Type**	**Forest Hydric Soil Width (m)**	**Magotha Width (m)**	**1.5 - 3.0m Width (m)**	**Landform**
L_a	10	NmA	225	75	-	Neck
L_a	11	NmA	250	0	-	Island
L_a	2	NmA	325	75	325	Interfluve
L_b	3	NmA	250	150	150	Interfluve
L_b	11B	NmA	800	50	350	Interfluve
L_b	12JB	NmA	100	325	200	Valley
L_b	BFF	NmA	1075	62.5	900	Valley
L_c	9	NmA	250	0	325	Valley
L_d	21B	BkA	-	62.5	700	Interfluve
I_a	12JA	MuA	-	12.5	-	Island
I_a	BSN	MuA	-	0	-	Neck
I_a	12T	BoA	-	25	-	Neck
I_a	13H	MuA	-	25	-	Island
I_a	17	MuA	-	25	100	Neck
I_b	21	NmA	32.5	32.5	180	Interfluve
I_b	22	DrA	32.5	50	400	Interfluve
I_c	13	BoA	-	25	-	Interfluve
I_c	18	BkA	-	25	75	Interfluve
I_c	28	MoD	-	12.5	125	Interfluve
H_a	8	BkA	-	0	100	Interfluve
H_a	26	DrA	125	0	75	Interfluve
H_b	5	BkA	-	50	75	Interfluve
H_b	27	MoD	-	50	150	Interfluve

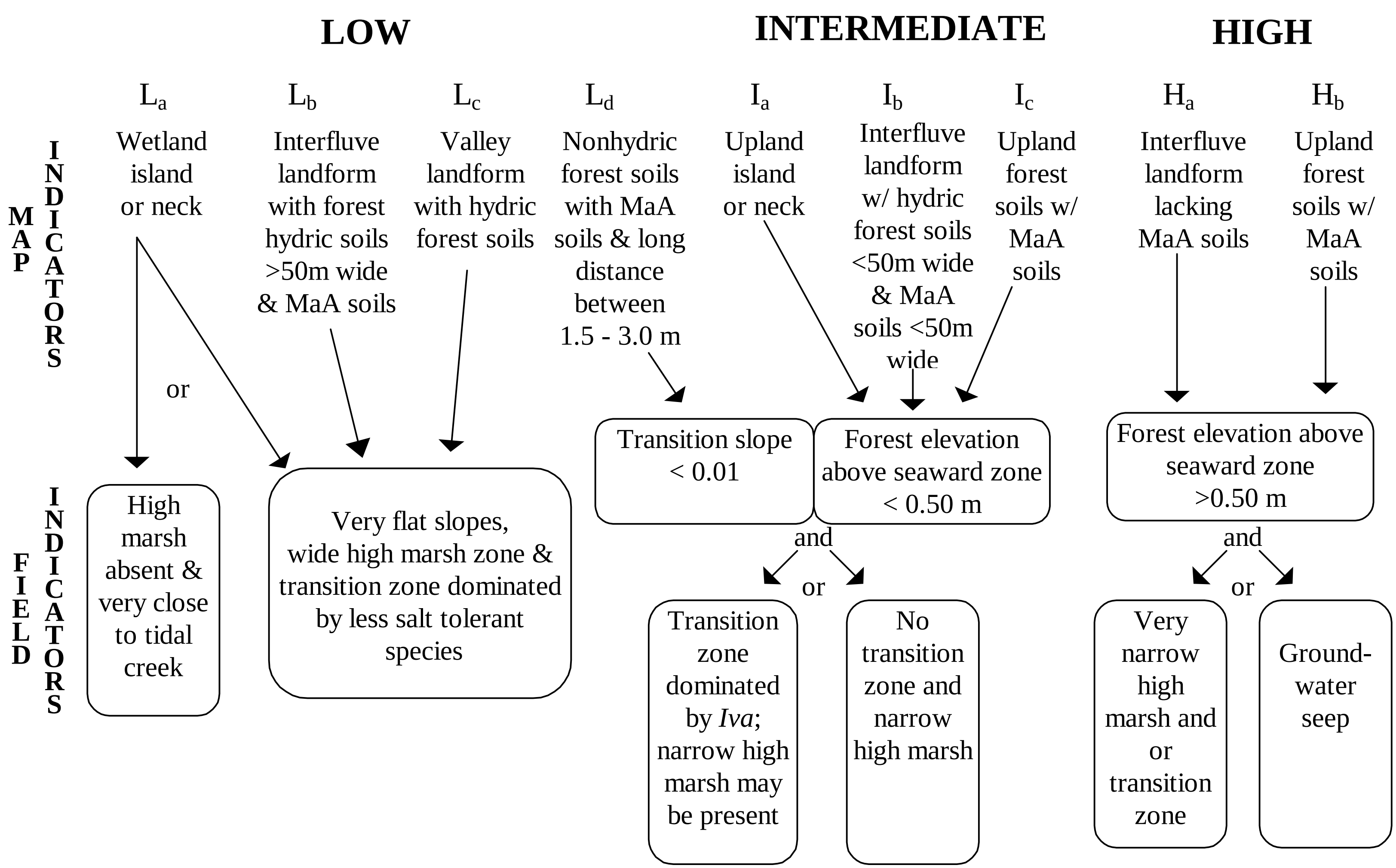


Figure 40. Map and field indicators for subclasses (a, b, c, d) of forest resistance groups (low, intermediate, high). I_c and H_b sites are not distinguishable from each other on topographic and soil survey maps. MaA refers to Magotha soil series, a hydric soil typically found in high marsh and transition zones.

I forest sites were also subdivided into three subgroups (I_a, I_b, I_c) using soil survey and USGS topographic maps. I_a sites occurred on island or neck landforms with nonhydric forest soils (Table 25). I_b sites occurred on interfluve landforms with hydric forest soils that were not very extensive in width (i.e. <50 m) and MaA that was not very extensive in width (i.e. <50 m). The three I_c sites had forests with nonhydric soils and MaA present, but distances between the 1.5-3.0 m contours were only moderate (75 m and 125 m) compared to the L_d site (700 m).

H forest sites were subdivided into two subgroups (H_a, H_b) using USGS topographic and soil survey maps. H_a sites occurred on interfluve landforms that lacked MaA soils (Table 25). Forest soil type was not an indicator of H_a sites. H_b sites were not distinguishable from I_c sites on maps. They both had nonhyric forest soils, MaA soils, and had moderately wide distances (75 m and 150 m) between their 1.5-3.0 m contour lines.

In addition to map indicators, field indicators were also identified for the forest resistance groups (Figure 40). L_a sites lacked a high marsh zone and their forests occurred very close (within 55 m) to a tidal creek. However, it is possible that wetland necks occurring along the Machipongo River valley may look more similar to L_b or L_c groups in the field because they have wide expanses of MaA soils located along them. L_b and L_c groups had very gradual slopes between their forest and marsh, very wide high marsh zones (>70 m), and had transition zones dominated by less salt tolerant species (*M. cerifera, J. virginiana, P. taeda*). The L_d forest site appeared similar to I forest sites in the field. These sites (L_d, I_a, I_b, I_c) had transition zones dominated by *I. frutescens* and had fairly narrow (<35 m) to nonexistent high marsh zones.

It may be difficult to distinguish H_a sites from I sites in the field without elevation measurements. H_a sites had very narrow transition zones that were dominated by *I. frutescens*, or *B. halimifolia* and *M. cerifera*. The key difference between H_a and I forests is that the elevation difference between H_a forests and their adjacent seaward zone was at least 0.57 m whereas it was always <0.4 m for I sites. H_a sites were easily distinguished from the L_d site in the field because the L_d site had a very gradual transition slope (0.007) compared to H_a sites (0.07 and 0.025). H_b sites had very steep slopes between marsh and forest, lacked a transition zone, and were in the only subgroup with groundwater seeps. The seeps were vegetated with *Phragmites australis* or *Scirpus* sp. Although I only sampled two H_b sites, I observed many steep transitions vegetated with *P. australis*. *P. australis* also occurred in places where freshwater creeks entered marshes, but these locations were distinguished from H_b sites because they had much more gradual slopes than the H_b sites. It is possible that H_a sites may also support groundwater seeps; however, I did not sample any that did.

The map indicators I identified were useful for characterizing the degree of resistance for 149 forest sites using USGS topographic and soil survey maps. Most of the forest to marsh coastline occurred along upland necks and islands (I_a); L_d and I_b forest sites were rare; and there were approximately the same number of L_a, L_b, L_c, I_c/H_b, and H_a forest sites (Figure 41). The central region had the largest number of forest sites adjacent to marshes, and had forests within all subgroups; however most of these had either low or

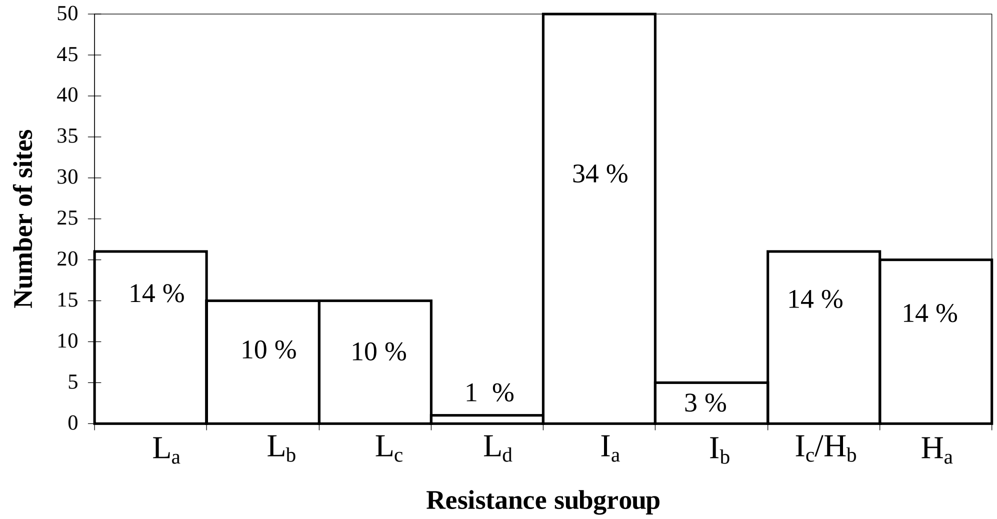


Figure 41. Number and percent of map sites within each forest resistance subgroup. Sites are comprised of all forests adjacent to marshes along 60 map transects and 7 additional field sites.

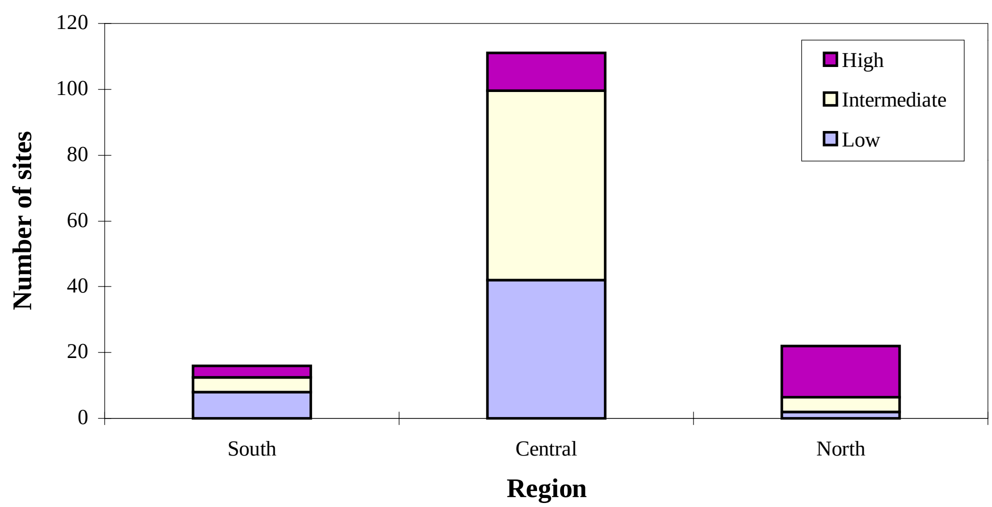


Figure 42. Number of sites within each forest resistance group by geographic region. Sites are comprised of all forests adjacent to marshes along 60 map transects and 7 additional field sites. I_c/H_b sites were split evenly between the intermediate and high resistance groups

intermediate resistance (Figures 42 and 43). Half of the coastal forests in the south region had low resistance and all of these were in the L_b subgroup (Figures 42 and 43). I_c and H_b sites made up the next largest proportion of the south region. Most of the coastal forests in the north region had high resistance (Figures 42 and 43).

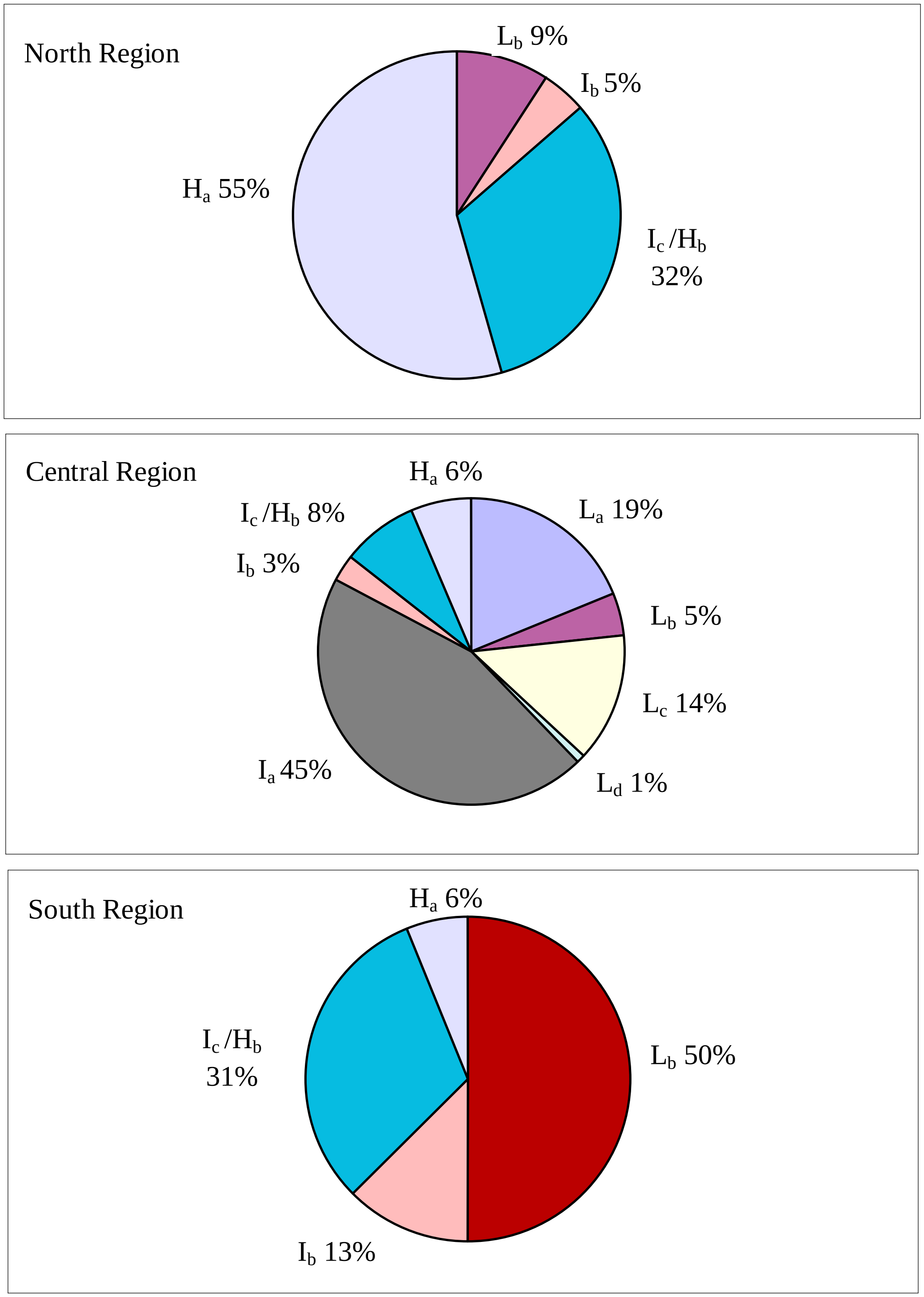


Figure 43. Pie charts showing percent of map sites in each forest resistance subgroup by geographic region. Sites are comprised of all forests adjacent to marshes along 60 map transects and 7 additional field sites.

5. DISCUSSION

The objective of this study was to characterize the mainland fringe of the VCR Megasite in terms of patterns where ecosystem state change is most likely to occur. Pattern characterization took place at two scales: a broad scale (10's of kilometers) that separated the Megasite into three geographic regions, and a smaller scale (10's of meters) that was more relevant to predicting state change. Patterns will be used to make predictions about the relative rate of state change within the different spatial scales.

In order to discern the broad pattern, soil types and elevation intervals were quantified for the three geographic regions using maps. Small scale patterns were established through a four step process. First, the four ecosystem states were characterized by gathering map and field data on their soils, vegetation patterns, and elevations. Forest and high marsh states were then classified, based on physical attributes, into three resistance groups according to their level of resistance (low, intermediate, high) to state change. Attributes of the three resistance groups, for each ecosystem state, were compared to determine if they were in different stages of a state change. Finally, a rapid assessment procedure is developed that uses only a few map and field indicators to identify forest resistance groups.

5.1 Outlook for Three Geographic Regions of Megasite

The central region has the most land area available for forest conversion to marsh because it has the most area at lower elevations (below 1.5 m and between 1.5 and 3.0 m), and the most area of hydric soils (Figure 44). Elevations <1.5 m are most likely to be

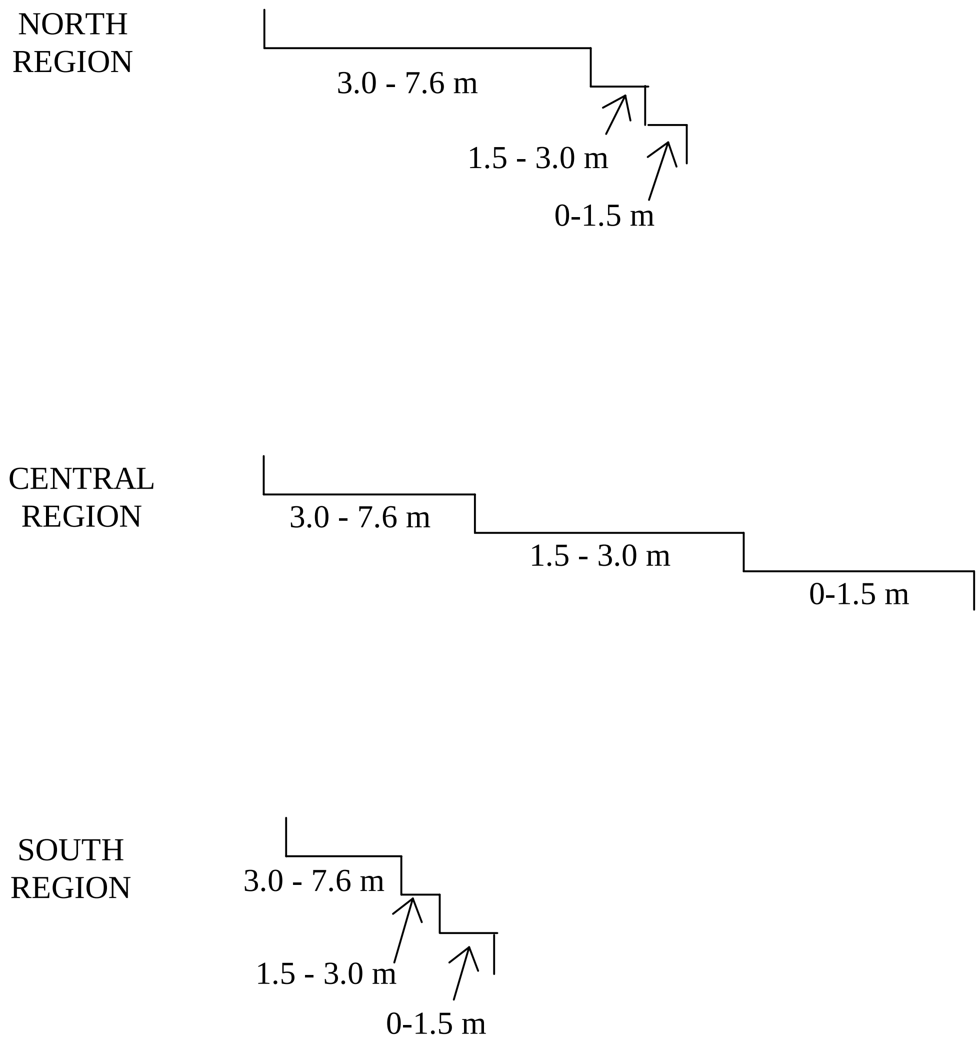


Figure 44. Cross section of terrace plain through the three geographic regions. Elevation intervals represent the average of each region and are proportionate among regions.

affected by rising sea level within the next 80 years, based on a rise of 5 mm/year (IPCC best estimate). At this rate, in 80 years sea level should be 0.4 m higher than present, and transition zone (currently elevated at 1.1 m) would have shifted 0.4 m upslope to replace forests located <1.5 m in elevation. Elevations between 1.5 and 3.0 m are unlikely to experience significant encroachment over the next 80 years, because they would still be situated above 1.5 m. Instead, they should become the new platform for marsh transgression in the following century. Coastal forests occurring on hydric soils are more susceptible to state change than those on upland soils because hydric soils are poorly drained. Poor drainage increases the duration of salts and reduced soil conditions, thus prolonging the time that vegetation is exposed to these stressors. Prolonged exposure to stressors causes forest vegetation die-back which leads to a more open canopy and less ground shading. These conditions encourage marsh species invasion and hence state change.

The north and south regions have very similar land areas of low elevations and transition soils, and have much less area available for forest conversion to marsh than does the central region (Figure 44). Although the south region has little area (389 ha) available for forest conversion to marsh, 50 % of its coastline has low resistance to state change, suggesting that the area available for conversion will change state fairly rapidly. In contrast, 91 % of the coastal forests in the north region, which also has little area (299 ha) available for forest conversion to marsh, has intermediate to high resistance to state change, and therefore will not change state as rapidly as the south region. Finally, 39 % of the coastal forests in the central region, which has the most land area (5,254 ha) available for forest conversion to marsh, has low resistance to state change and will likely undergo a transformation in the next 50 - 100 years. Based on these results, the north and south regions are prone to experience a net loss in marshes over the next 100 years while the central region is likely to experience a net loss in forests.

5.2 Ecosystem State Characteristics

In general, four ecosystem attributes (species richness, physical vegetation structural complexity, soil organic matter, soil salinity) changed with each successive ecosystem state change (Figure 45). The degree and direction of each attribute change depends on the specific state change under consideration, and are believed to result from differential flooding regimes among the states. Consequently, each state had a unique suite of characteristics.

Coastal forests were dominated by various hardwood and coniferous trees, had an average basal area of 17 m^2/ha, and a full tree canopy cover. There were few shrubs, little herbaceous ground cover, and rare occurrence of halophytic plants. Soil organic matter and salt concentrations in the forest soils were relatively low, on average, compared with the other states, and evidence of reduced soil conditions varied depending on soil drainage type.

As forests become exposed to estuarine flooding for sufficient time, they are replaced with transition zones. Transition zone attributes resemble a mixture between the

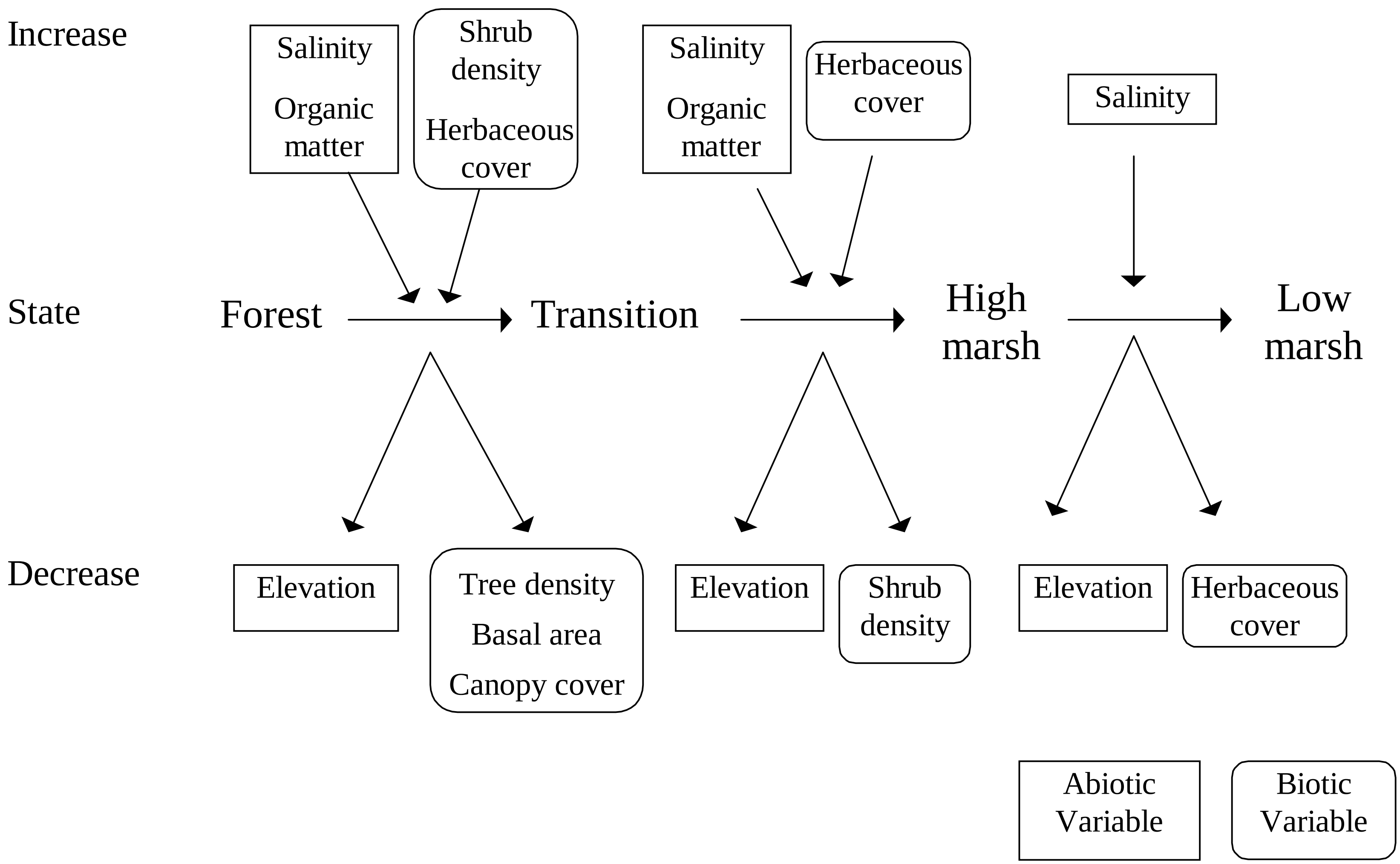


Figure 45. Summary of changes that occur with each state change in response to rising sea level. Variables that increase with state change are shown on top and variables that decrease or are lost with state change are shown on bottom.

forest and high marsh, in addition to having characteristics unique to the zone. Dead trees and tree stumps dispersed throughout the transition are evidence that it replaced what formerly was forest. Shrubs were the dominant vegetation in the transition zone, but a few trees and some herbaceous ground cover also contributed to cover. Trees, where present, had little basal area, were either *Pinus taeda* or *Juniperus virginiana*, and generally provided little canopy cover above 3 m. Transition zone shrub species were comprised of both halophytes (*Baccharis halimifolia* and *Iva frutescens*) and glycophytes (*Myrica cerifera*, *J. virginiana*, *Pinus taeda*). Transition zone herbaceous cover averaged 52 % and was composed predominately of high marsh species (*Spartina patens*, *Distichlis spicata*, *Juncus* spp.), but also had some fairly salt intolerant species (*Panicum virgatum* and *Setaria viridis*). Soils in the transition zone had slightly deeper organic rich horizons and higher salt content than the forest, but both were generally lower than the high marsh. Most soils in the transition zone showed signs of reduced conditions.

As the land surface becomes flooded more often by spring tides, severe storm events, and precipitation (Stasavitch 1998), transition zone shrubs and trees die and are replaced almost exclusively with herbaceous species, typical of the high marsh. Dead shrubs dispersed throughout the high marsh indicate that replacement of the transition zone has occurred. High marsh herbaceous species composition was dominated by a few halophytes: *S. patens*, *D. spicata*, and *J. roemerianus*. Both soil salinity and organic matter content and depth were much higher in the high marsh than the transition or forest, and all high marsh soils showed signs of reduced conditions.

As the land surface becomes flooded daily with estuarine tides, high marsh is replaced by low marsh. Low marsh characteristics from this study do not represent the entire low marsh state, but rather the 24-m width zone adjacent to high marsh. Low marsh was colonized by a monospecific stand of *Spartina alterniflora* which covered on average 60 % of the ground. No trees or shrubs were present in this zone but the occurrence of tree stumps were again evidence the area once had been forest. Soil salinity and organic matter depth were greater in the low marsh than high marsh but percent organic matter was lower in the low marsh than high marsh. Finally, all low marsh soils had indicators of reduced conditions.

Most ecosystem attributes measured in this study appear to be changing in the direction projected by the Brinson et al. (1995) state change model. Attribute changes consistent with the authors' state change model include (1) loss of woody species and species richness, (2) loss of vegetation vertical complexity, and (3) increase in salinity with seaward state changes. However, results from this study differ from those proposed in the state change model (Brinson et al. 1995) for soil organic matter dynamics. Brinson et al. (1995) hypothesize that soil organic matter should increase with state change from forest to high marsh and then decrease with state change from high marsh to low marsh. Results from this study show that soil organic matter increased as forest was replaced by high marsh. However, soil organic matter was not always lost as high marsh was replaced by low marsh. Furthermore, individual sites (versus state averages) did not always conform to trends found in this study or those proposed by Brinson et al. (1995). For example, not all high marshes developed organic rich horizons. These discrepancies suggest that mechanisms driving state change may not be as simple or predictable as described by Brinson et al. (1995).

5.3 Causes of State Change

Soil and vegetation characteristics altered by longer flooding regimes are due to both abiotic and biotic influences. Flooding frequency and duration increase with each seaward state change (Stasavitch 1998), and these hydrodynamics act to change soil characteristics. First, increased estuarine flooding introduces a higher concentration of salts to the soils. Also, a longer hydroperiod reduces oxygen concentrations, causes lower soil redox potentials, and results in higher reduced Fe, Mn, and S ion concentrations (Mohanty and Dash 1982). Soil physiochemical changes associated with longer hydroperiods, impede organic matter decomposition, and result in increased organic-rich stratum thickness with each seaward state change. A reduction in percent organic matter of low marsh soils, without a similar reduction in organic matter depth, may be due to greater mineral sedimentation rates from regular tidal flooding.

Vegetation structural complexity and species richness, also, are affected by soil physiochemical changes. Reduced soil conditions and salt accumulation have been shown to stress or limit production in marsh grasses (Pearcy and Ustin 1984, DeLaune et al. 1987, Koch and Mendelssohn 1989, Bertness and Ellison 1987, Bertness 1992, Broome et al. 1995) and woody vegetation (Penfound and Hathaway 1938, Kjerfve 1979, Brinson et al. 1985, Salinas et al. 1986, Conner et al. 1989, Young et al. 1994, Hacker and Bertness 1995, Conner et al. 1997). As these stressors increase in each seaward zone, the number of species able to tolerate them decreases as indicated by decreasing species richness. This point is made obvious by the fact that the low marsh is typically a monospecific stand of *Spartina alterniflora*. Miller and Egler (1950), Eleuterius (1972), Jaworski and Tedrow (1985), and Hmieleski (1994) have described the same trend of declining species numbers, and hence structural complexity, with closer proximity to the sea. It is not always clear which stressors are most controlling, and likely they act in concert to produce the distinct vegetation zonation in these coastal wetlands (Kurz and Wagner 1957, Frey and Basan 1978).

In addition to the large role of physiochemical soil properties in plant zonation, competition between species also plays a role (Bertness 1991). Because of height advantages, trees are able to out-compete shrubs for light, and shrubs are able to out-compete marsh grasses for light (Brinson et al. 1995). However, in each scenario, the better light competitor is more sensitive to physiochemical stressors. So as trees become stressed and die, shrubs become abundant, and as shrubs become stressed and die, grasses become abundant. Marsh grass zonation is also a reflection of both abiotic and biotic controls. *Spartina patens* is restricted to the high marsh because of physiochemical stressors in the low marsh, whereas *S. alterniflora* is excluded from the high marsh state by competition for space with high marsh species (Bertness and Ellison 1987).

5.4 Resistance Group Classification

The four variables used to classify forest resistance groups were highly intercorrelated, raising the question of the value of the redundancy. Variables used in the classification were chosen to represent a forest's ability to resist brackish water flooding or to drain brackish waters once flooded. For the two variables used to describe forest elevation (elevation above MSL, elevation difference between forest and adjacent seaward zone), redundancy was useful for both practical and conceptual reasons. In terms of practicality, elevation difference between the forest and adjacent seaward zone data was much easier to obtain than elevation above MSL because a permanent bench mark was not required. I was able to obtain reliable data for all sites using this variable unlike elevation above MSL data where I have measured values for some sites and estimated values for others. However, elevation above MSL data was necessary because it served as a standard for comparison between sites. Conceptually, elevation difference between forest and adjacent seaward zone may be more representative of the elevation at which forest will convert to transition because it takes into account individual nuances of a site that I did not incorporate. For example, direction of forest orientation (northeast facing, west facing, etc.), distance to tidal source, or specific site alterations may all have some influence on the rate of forest state change but these were either not measured or were unreliable due to inconsistent patterns.

The two variables used to describe the forest's drainage potential (slope and soil type) represent different scales that influence the drainage of brackish water. Soil drainage type is likely related to the relative duration brackish water remains within soil pore spaces. In contrast, slope defines the hydraulic gradient of the site and therefore the direction and rate of water flow both below and above ground (Hmieleski 1994). Because slope has been shown to overcome drainage restrictions for some but not all soils (Harvey and Odum 1990), soil drainage type was weighted less than slope.

The classification criteria appeared to be effective in separating three fairly discrete groups with minimal overlap between resistance groups for the three numerical classification variables. Although the groups were distinct, their scores and ranks essentially formed a continuum from low to high. It is not clear why site 26 was grouped closer to I sites in the ordination plot. The ordination was based on standardized scores compared to the data set mean. It is possible that it compressed the remaining sites because the other three H sites were much different from the mean in the two elevation variables.

Organic matter characteristics (depth and percent) were added to elevation and slope variables for classification of high marsh sites because organic matter is both a result of and a control over variables affecting high marsh resistance to state change. Organic matter accumulation results from poor drainage and therefore is an indicator of drainage potential. However, once organic matter has accumulated it exerts control over marsh drainage because its high water storage capacity. As a result, organic matter remains saturated for long durations and may retain salts for longer durations than mineral soils. Furthermore, organic matter can influence marsh elevation due to its low bulk density and susceptibility to decomposition. Sites with deep organic horizons have a high potential for rapid elevation decline if organic layers decompose or erode. Also, the rhizosphere, which contains live material and is included in the organic rich horizon, loses volume when plants die. As elevation declines, the relative rate of sea level rise increases and subsequently the relative rate of state change. For example, DeLaune et al. (1994) reported a 15 cm elevation decline over two years from peat collapse in a Mississippi Deltaic marsh.

Unlike the three forest groups, high marsh groups were not distinctly different from each other for all classification variables. Both elevation difference between high marsh and low marsh and slope of high marsh, and percent organic matter and depth of organic matter had the same grouping results. It appears that using just elevation above MSL, high marsh slope and depth of organic matter would have resulted in the same grouping of sites. Results suggest that having both gentle slopes and low elevations are necessary to sustain the hydroperiod required for deep organic horizons to form. Neither intermediate resistance high marsh sites that had gentle slopes but high elevations, nor high resistance high marsh sites that had relatively low elevations but a steep slopes, had deep accumulations of organic matter.

Although I was unable to identify map indicators of high marsh resistance groups, they can be detected with minimal effort in the field. L high marsh sites can be identified as having deep organic horizons (i.e. >20 cm) and gentle slopes; I sites have little to no organic matter and gentle slopes, and H sites have steep slopes and no organic matter.

5.5 Stages of State Change for Resistance Groups

Low resistant forests appeared to be in a more advanced stage of state change to transition than I or H forests. Low resistant F1 plots (F1 = seaward-most forest plot) had vegetation and soil characteristics more similar to the transition zone than I and H forests.

L forests had higher shrub densities and very low hardwood importance values. In contrast, I and H F1 plots had very few to no shrubs, and hardwoods composed a large portion of the woody species composition. Since dead vegetation components and canopy cover did not differ among the three forest resistance groups, it is not apparent why shrub density is higher for L forest sites. It is possible that my measure of canopy cover was not sensitive enough to distinguish between functionally different levels of light penetration. Rather, leaf area index, a ratio of leaf area to ground area, may be more useful in determining light penetration. Alternatively, higher shrub densities may reflect slower growth rates in *P. taeda* and *J. virginiana* for L forests rather than recent invasion of new individuals as a result of increased sunlight penetration to the forest floor. L forests had the deepest organic rich horizons with the highest organic matter percentages; however, because L forests were defined as those with poorer drainage potential, these results are not surprising. Finally, higher salinities in L forest soils suggest brackish water intrusion is either occurring more frequently or is not compensated for as quickly by flushing.

Differences between attributes of transition zones forming seaward of forest resistance groups support the assumption that L, I, and H forests are in different stages of state change. Compared with I and H groups, transitions occurring between L resistant forests and marsh had characteristics more similar to forest, indicating they may have formed more recently. In contrast, I transitions had characteristics least similar to a forest, suggesting their forests had not undergone recent change. Similarly, Hmieleski (1994) reported a sharp zonation between transition and forests occurring on steep slopes, and a wider ecotone between forest and its transition occurring on gentle slopes. Vegetation and soil characteristics for transitions occurring next to H forests were more similar to I than L transitions. However, because the H transition data set is represented by only two sites, it may not cover the range of variation along the Megasite.

Transition zones adjacent to L forests had the most remaining trees, highest basal area, highest canopy cover, and the lowest ratio of vegetated to unvegetated ground cover compared with transitions adjacent to I or H forests. Also, woody species composition of L forest transition zones was composed of glycophytes (*M. cerifera*, *J. virginiana*, *P. taeda*) whereas species dominating transition sites adjacent to I and H forests were more salt tolerant. Moreover, the fact that I transitions similar to L transitions in terms of depth and percent of organic matter, even though they started from a forest with almost no organic matter, may imply they have been in the transition phase longer.

Unexpectedly, width of the transition zone was not always related to resistance group. L forests were expected to have wider transition zones than I or H forests as an indication that more area was undergoing state change. In fact, the forest with the lowest slope had a transition zone width of only 4 m. A possible explanation for the lack of transition width along these gentle gradient slopes is that dead trees and shrubs were eliminated through an episodic event such as a fire. If this occurred, then transition replacement by high marsh likely took place at a faster rate as competition for sunlight was eliminated. In fact, regardless of transition width, all L forest sites had very wide high marsh zones. Any transition present today would then represent state change that has occurred since the last fire. Young (1995) described state changes in coastal forests of North Carolina as occurring in a punctuated stepwise fashion in response to a large disturbance. Although a gradually rising sea level is the underlying mechanism driving forest state change, large scale forest conversion to marsh does not occur until woody vegetation is eliminated through disturbance (Young 1995). Alternatively, lack of transition width may reflect a relative stability of the forest, but I can offer no explanation for their stability. Despite site history, poor drainage and accessibility to flooding waters renders L forests very vulnerable to changes in the near future. As expected, slope was steep enough between H forests and marsh to exclude a transition zone along two H sites and to have only very narrow transition formation along the other two H sites.

Transition zone groups (L, I, H) had physical characteristic patterns similar to high marsh resistance groups (L, I, H). L and I transitions had relatively flat slopes and H sites had very steep slopes. Also, I transition sites were located at the highest elevations. Evidently slopes are gentle enough between forest and marsh to provide a platform for the development of a transition zone. Because I forest elevations are higher than L forest elevations, it seems reasonable that I transitions would be elevated above them. In contrast, due to steep slopes between H forests and marsh, transition zone development is limited to lower elevations, at least for the two sites that were sampled.

In the transition zone there was no correlation between salinity and the density of dead trees or stumps. It seems reasonable that if trees die in the initial phase of transition formation, then by the time the transition zone accumulates higher salinities, dead trees would have already fallen and decomposed. Nonetheless, it is not certain how long it takes for dead trees to fall and disappear from the transition zone. The rate of this process is apt to be highly variable depending on the frequency of storms or other disturbances

(Young 1995). Still, the general lack of dead trees (snags) in this study's transition sites indicates that if dead tree removal occurs gradually over time through decomposition, then most of these sites must be very old. The other possible scenario, as already mentioned, is that some recent large disturbance (i.e., hurricane, northeaster, fire) has removed most dead trees from these transitions. If this were the case, then the fact that a few more dead trees are present in L sites implies these transitions formed more recently and have not had sufficient time for dead tree removal to occur.

Site 12JA, a very small island, had a superabundance of dead trees indicating it has recently undergone state change. It is likely that once islands or necks reach a sufficiently small size, they lose most resistance to state change regardless of elevation or soil type because their fresh water supplies are inadequate to combat encroaching salts. It is unknown what the critical size of these landforms is before they lack resistance to state change.

In contrast to dead tree and stump density, dead shrub density was positively correlated with salinity for both shrub size classes. Hacker and Bertness (1995) showed that increasing anoxia and salt concentrations decreased the biomass, growth, and survival of *Iva*. I transitions had significantly higher dead shrub densities compared to L and H transitions which virtually lacked dead shrubs. Although salinity did not significantly differ between the three transition groups as a whole, three of the seven intermediate transitions had relatively high salinities. Higher salinity can not be explained by physical features alone because two sites had gentle slopes but were at high elevations, and the other had a steep slope but was at a low elevation. I hypothesize these sites have been in the transition state longer and therefore have had more time to accumulate salt. The lack of high salinities and high densities of dead shrubs in L and H transitions may be due to different reasons. Most likely, shrubs are not dying in H transition sites because groundwater discharge from the steep slope can act to maintain low salt concentrations (Hmieleski 1994). In comparison, if L transitions have formed more recently, they have not had a chance to accumulate salinities sufficient to stress or kill shrubs. Alternatively, fire in transition zones could act to eliminate standing dead shrubs.

High marsh resistance groups also appear to differ in their stages of state change. Other than variables used to classify sites, soil salinity varied the most among the three high marsh resistance groups. Higher soil salinities in L high marsh sites, relative to I and H sites probably resulted from poorer drainage due to the high organic content of their soils. In turn, higher salinities presumably led to low shrub density in L sites, with exception for site 27. Although the highest shrub densities occurred in high marsh sites with relatively low salinity, all sites with low salinity did not have high shrub densities.

The lack of dead trees or shrubs in the L high marsh sites indicate they have been in the high marsh state longer than I high marsh sites. L high marsh sites had almost no dead shrubs remaining with exception of two sites which both occurred adjacent to H forest sites. It is possible the steep slopes between H forests and marsh provided enough groundwater discharge to allow shrubs to survive longer than those seaward of I or L forests. In contrast, most I and a few H high marsh sites had quite a few dead shrub remnants suggesting they were in a more recent stage of change.

Similar to its transition zone, the high marsh for site 12JA had a superabundance of dead shrubs, dead trees, and stumps. Site 13H, which is a somewhat larger island, also had high densities of dead standing vegetation in its high marsh zone, but there was evidence this marsh had been recently burned. Therefore, higher densities of dead standing vegetation may have been a result of fire rather than rising sea level if fire intensity was sufficient to kill shrubs but not eliminate their above-ground biomass.

5.6 Seaward States of Forest Resistance Groups

Low resistant forests tended to have L or I high marsh zones seaward of them, and regardless of high marsh classification, all high marshes seaward of L forests were very wide. This phenomenon may further increase the susceptibility of L forests to state change by facilitating estuarine water transport to the forest. The only two L forests that did not conform to this description were on the wetland island and wetland neck (Tables 24 and 25). Neither of these two sites had high marsh seaward of them but instead were located very close to tidal creeks. High marsh was lacking at these sites because the slope between the transition and low marsh was moderately steep. However, their proximity to a tidal creek, in addition to relatively low elevations, probably makes them even more susceptible to state change than forests with wide low resistant high marsh zones. In fact, the highest forest salinity (4.7 ppt) measured occurred on the wetland island.

Site 21B was somewhat of an outlier to the L forest group because it had the narrowest high marsh width of L forest sites with high marsh, lacked organic matter in its high marsh, had a transition zone dominated by *Iva frutescens*, and was the only L forest with nonhydric soils. Due to its lack of soil organic matter, the high marsh of site 21B will not likely affect the susceptibility of the forest to state change.

In contrast to L forests, I forests tended to have I or H high marshes seaward of them, and none of these marshes were very wide. Although narrow high marsh zones position I forests closer to the tidal source, I forest slopes and elevations are probably sufficient to compensate for the shorter proximity. Of the I high marshes, those occurring adjacent to I forests were the most resistant, and none had organic horizons >10 cm. For these reasons, high marshes seaward of I forests probably will not affect the rate at which I forests undergo state change.

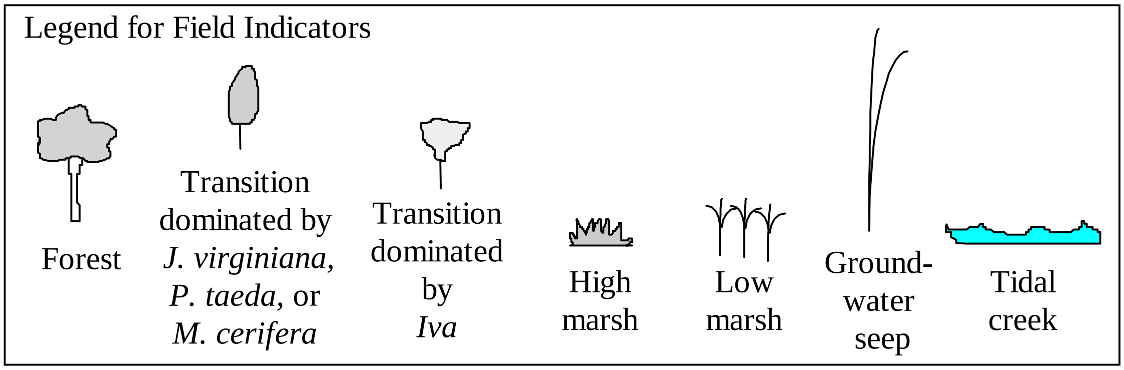
Both H forest sites with high marsh had L resistant high marshes. Although these high marshes are expected to convert to low marsh or open water at relatively rapid rates, they probably will not affect the rate at which the H forests change. This is because H forests are elevated so much higher than their adjacent marshes that change in marsh resistance class will not affect the forest.

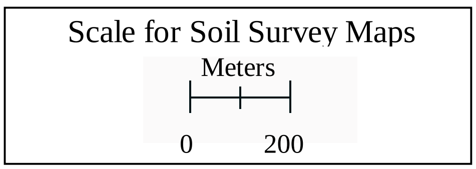
Both sites with groundwater seeps occurred just seaward of H forests. Despite being positioned at low elevations, and having deep organic horizons, groundwater seeps are probably fairly resistant to state change because they receive a constant supply of fresh water. Fresh water acts to dilute salts from estuarine tidal waters and provides conditions favorable for organic matter accumulation that appear to occur at a rate sufficient to keep pace with rising sea level. Nonetheless, their resistance should not affect the resistance of their adjacent forests to state change because H forests occupy much higher elevations.

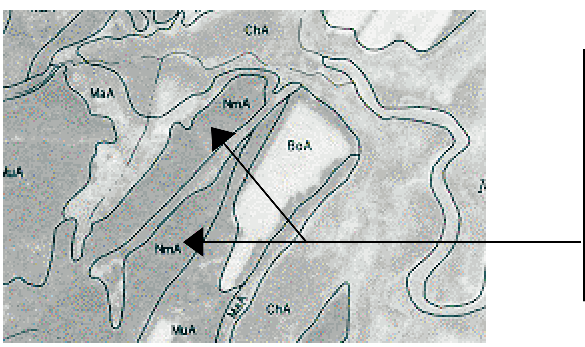
5.7 Map and Field Indicators of Forest Resistance Groups

By dividing forest resistance groups into subgroups, I was able to identify indicators on maps and/or in the field for all resistance groups (Figure 46). Primary map indicators, all of which were detectable on USDA soil survey maps, include landform type, forest soil drainage type (hydric or nonhydric), forest soil series width, and presence and width of the MaA soil series (high marsh soil series). Field indicators identified include width of high marsh; transition width, slope, and species dominance; elevation difference between forest and adjacent seaward zone; and presence of groundwater seeps. Both types of indicators should be used for rapid site assessments because map indicators contribute to efficiency and field indicators contribute to accuracy and precision.

Figure 46. Examples of each forest resistance subgroup illustrated on soil survey maps and field cross sections. N/A indicates variable is not used as an indicator for that subgroup. Elevation difference is measured between seaward forest edge and the seaward edge of the adjacent zone. Slope is measured between forest edge and low marsh-high marsh boundary.

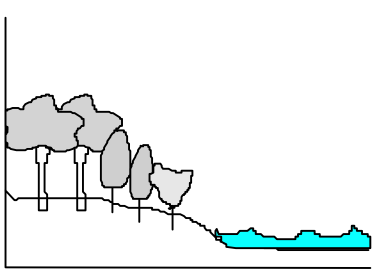






L_a Map indicators

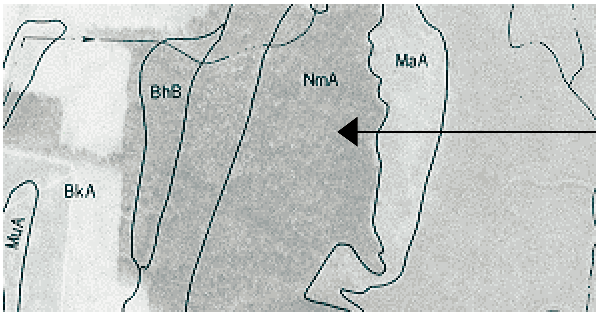
Landform: neck/island
Forest soil: hydric
Magotha: N/A



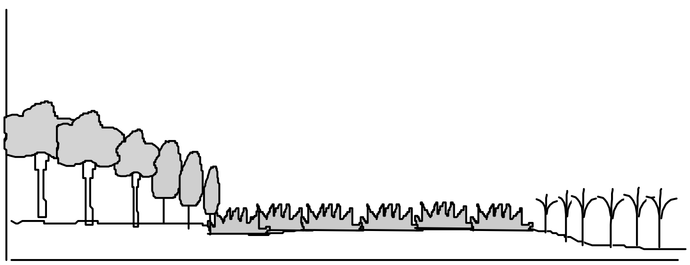
L_a Field indicators

High marsh: N/A
Transition: N/A
Slope: <0.18
Elevation difference: N/A
Very close to tidal creek
or may look same as L_b & L_c shown on next page

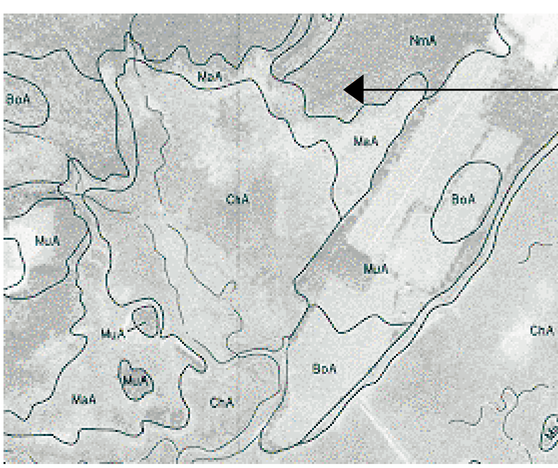
Figure 46. Continued.



L_b Map indicators
Landform: Interfluve
Forest Soil: hydric >100 m wide
Magotha: present

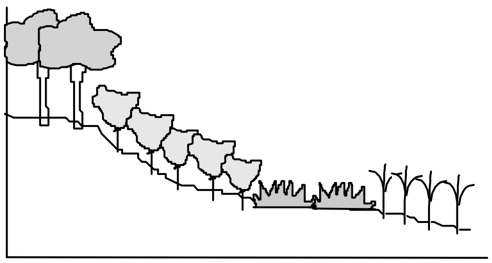


L_a, L_b, or L_c Field indicators
High marsh: very wide
Transition: dominated by *Pinus taeda*, *Juniperus virginiana*, or *Myrica cerifera*
Slope: N/A
Elevation difference: N/A



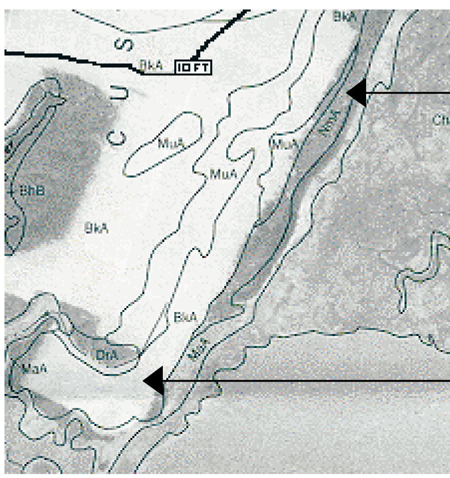
L_c Map indicators
Landform: valley
Forest soil: hydric
Magotha: N/A

Figure 46. Continued.



I_b Field indicators

High marsh: very narrow or absent
Transition: dominated by *Iva frutescens*
Slope: >0.01
Elevation: <0.5 m



I_b Map indicators

Landform: interfluve
Forest soils: hydric <35 m
Magotha: present

L_d Map indicators

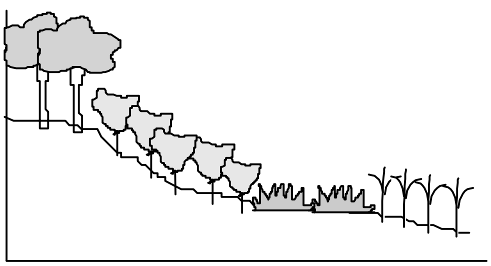
Landform: interfluve
Forest soils: nonhydric
Magotha: present
Wide distance between 5 and 10 ft contour interval

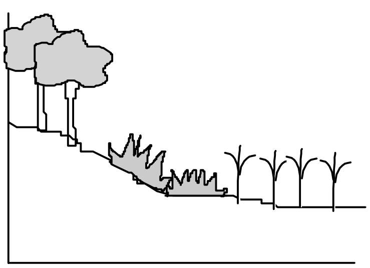
L_d Field indicators

High marsh: ≤35 m
Transition: dominated by *Iva frutescens*
Slope: <0.01
Elevation difference: <0.5 m

Figure 46. Continued.

I_a Map indicators
Landform: neck/island
Forest soil: nonhydric
Magotha: N/A

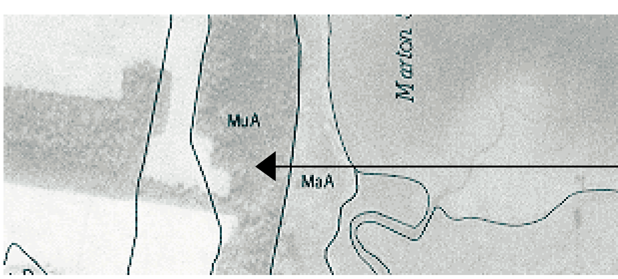




I_a or I_c
Field indicators
High marsh: narrow or absent
Transition: dominated by *Iva frutescens*
Slope: N/A for I_a; >0.01 for I_c
Elevation difference: <0.5 m

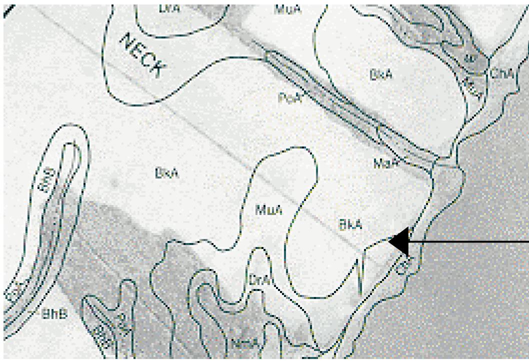
or

High marsh: narrow (<35 m)
Transition: absent
Slope: N/A for I_a: >0.01 for I_c
Elevation difference: <0.5 m

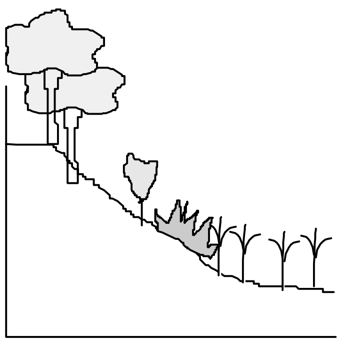


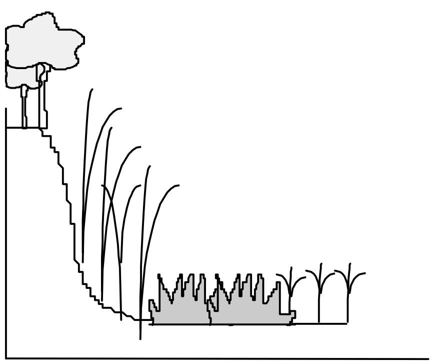
I_c Map indicators
Landform: valley or interfluve
Forest soil: nonhydric
Magotha: present

Figure 46. Continued.



H_a Map indicators
Landform: valley or interfluve
Forest soil type: N/A
Magotha: absent

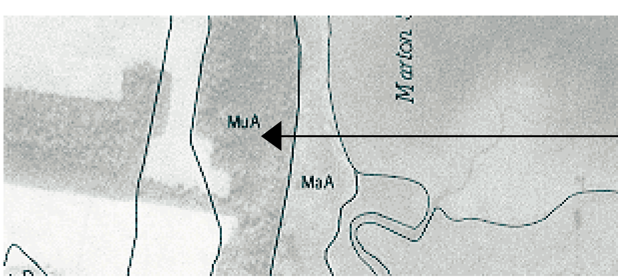




H_a or H_b
Field Indicators
High marsh: very narrow (<15 m) or absent
Transition: very narrow (<15 m) or absent
Slope: N/A
Elevation difference: >0.5 m

or

High marsh: N/A
Transition: absent
Slope: N/A
Elevation difference: >0.5 m
Groundwater seep present



H_b Map indicators
Landform: valley or interfluve
Forest soil: nonhydric
Magotha: present

Two scenarios exist where map indicators are insufficient to distinguish between forest resistance groups. First, L_d, I_c and H_b sites all have nonhydric forest soils landward of MaA soils and, therefore, are not readily distinguishable from each other (Figure 40, Table 25). L_d sites can be distinguished from I_c and H_b sites if topographic maps are used because L_d sites have very wide (700 m) 5-10 ft contour intervals whereas I_c and H_b sites do not. However, L_d sites are rare, so it may be more practical to rely on the use of field indicators to differentiate between the subgroups. Second, although the 23 field sampled sites included every variety of soil and landform combination, all lengths of the hydric soil types were not sampled. All forests sampled with hydric soils $\geq$100 m in width were classified as low resistance and both forests with hydric soils $\leq$32.5 m were classified as intermediate resistance. Because I did not sample any forests with hydric soil widths mapped between 32.5 and 100 m, I am not sure where the division between I and L forests would occur between these two widths. For purposes of characterizing maps in this study, I estimated the division to occur at 50 m. This is closer to the lower width end of the scale (32.5 m), because generally wide bands of hydric soils indicate low slopes and poor drainage. Nonetheless, for site determinations, forests with hydric soil map widths between 32.5 and 100 m should be examined closely in the field.

Using a single field indicator alone is not sufficient to correctly identify resistance groups because some field indicators overlap among resistance groups, and indicators are based on field data that did not encompass the full range of field attributes. For example, both of the wetland island/neck landforms that I sampled lacked a high marsh. It is highly possible that the larger wetland necks in the Machipongo River watershed appear very similar to the L resistance groups with wide high marsh zones because they have wide bands of MaA soils. Furthermore, it is possible for L resistant forests to occur in locations where wide high marsh development would be restricted due to lack of area at lower elevations. This is especially probable for L forests positioned near ridges of upland necks. Under these conditions, lack of high marsh does not imply higher resistance. This scenario was compensated for by using hydric forest soils that fringe valleys, regardless of MaA soil width, as map indicators for low resistance forest sites. Still, this example illustrates how a single indicator may lead to placing a given site into the incorrect resistance group. Furthermore, a transition zone dominated by *Iva frutescens* is used as an indicator for identifying several different subgroups spanning all three forest resistance groups. Therefore, this indicator must be used in conjunction with map indicators for appropriate resistance group identification.

Landform type alone does not confer resistance because all three forest resistance groups can occur along both valley and interfluve landforms and L and I resistance groups occur along necks and islands. Still landforms are useful in identifying resistance groups because the likelihood of specific L, I, or H physical characteristics occurring within certain landform positions is predictable. For example, valley landforms develop as marsh migrates up low gradient streams. Typically forests with hydric soils in a valley setting have gentle slopes. Therefore, valley landforms with hydric soils in the forest, regardless of presence of MaA soils, are predicted to have low resistance to state change. In contrast, forests with hydric soils along interfluve landforms occur in locations with both gentle to steep slopes. Therefore, within interfluve landforms, the presence and width of

MaA soils are used to estimate land slope (i.e. a wider Magotha series means more gentle slope).

Islands and necks are in a more advanced stage of drowning than the mainland and therefore have their own set of resistance indicators. Neck and island landforms do not have land elevations as high as the mainland and consequently locations with both steep slopes and high elevations were not detected on them. Because islands and necks generally lack the criteria necessary for high resistance, forest soil type (hydric vs. nonhydric) proved to be effective in distinguishing between I and L resistance groups. It is possible that locations exist along necks that meet high resistance criteria, but none occurred in any of the locations I sampled.

5.8 Coastal Forest Resistance Classification Procedure

Using map and field indicators, a procedure to rapidly identify a given coastal forest's resistance to change in state due to rising sea level was developed. The procedure has been named Coastal Forest Resistance classification (CFR classification). The CFR classification procedure consists of two keys in the form of flow charts and supplemental information that aid in chart use (APPENDIX Q). The key endpoint is a classification for a given forest as low, intermediate or high in its potential for resisting state change. Resistance can be expressed at two levels of precision: an assignment to a generic resistance group (L, I, H) or its position within a specific resistance group. The first part of Key 1 (Key 1A) uses indicators from soil survey maps, which are published for every county and are free to the public, to identify a resistance subgroup. The second part of

Key 1 (Key 1B) utilizes field indicators to verify the resistance subgroup identified with Key 1A. If field indicators do not match the subgroup chosen in Key 1A, the key directs the user to either a different resistance subgroup or to Key 2. Key 2 is the scoring procedure that was used to classify sites in this study (Table 4). It requires the most data but provides the highest accuracy and precision. Individuals desiring the more precise option are directed to Key 2 from the start. Finally, the CFR classification provides a statement on the likelihood for forest state change, given a 15 cm rise in sea level, for each resistance group.

Interpretation of state change rate between resistance groups should be done with caution. As already mentioned, groups represent different positions along a continuum. Thus it is possible that overlap in the rate of state change may occur between groups with different resistance classifications. For this reason, it may be advantageous to use Key 2 to determine whether a site is in a borderline position for its resistance group. Furthermore, several of the values used in the classification were assumed to be relevant, rather than based on measurements known to have field significance. Although these assumed values were useful in partitioning sites into groups, it is not clear how differently each group will actually respond to rising sea level. Present-day comparisons between average values of data from forest resistance groups indicate each group is responding differently to rising sea level. However, these results are based on group averages and so may or may not represent how an individual site will respond to rising sea level.

Presumably the CFR classification should be applicable in other geographic locations with similar coastal systems. However, testing of the classification should be done before implementation. Verification of the CFR classification can be done by cross-checking map and field indicators for a reasonable number of sites within all forest resistance subgroups present. If a large number of sites cannot be identified using only Key 1 then map and/or field indicators should be modified. Modification may consist of eliminating and/or adding landforms, specific soils series, or indicator species. Because most of these indicators were generic they should be fairly easily modified. For example, locations lacking relict sand ridges may use only valley and interfluve landforms as indicators. Also, specific soil series will likely differ depending on location; however, generic differentiation between forest soils types (i.e., hydric or nonhydric) and high marsh soils (Magotha = Natraqualfs) should allow them to be adaptable to similar coastal systems. Salt marsh species composition is fairly consistent geographically; however, species indicators used in this study were based on each species level of salt tolerance and could be changed where necessary.

The CFR classification would not be appropriate for use in determining forest resistance to state change for all coastal forests. For example, along the Albemarle and Pamlico Sounds of North Carolina, there are only a few narrow tidal inlets between barrier islands and the sea. Thus tides are primarily irregular wind tides rather than regular astronomical tides. Erosion is a large physical force in wind tide (wave) dominated coastal systems and is not considered in the CFR classification.

Furthermore, unlike forests at the VCR, the resistance of these North Carolina coastal forests to state change is almost solely a function of their ability to accumulate peat through autogenic accretion at rates comparable to rising sea level (Moorhead and

Brinson 1995). Most of these forests are situated at very low elevations, lack a source of allochthonous sediment, and rest on deep organic soils (Moorhead and Brinson 1995, Young 1995). Because a platform suitable for marsh migration is lacking, and the underlying substrate is oxidizable organic matter, these coastal forests convert to open water rather than undergo the sequence of state changes to low marsh assumed by the CFR classification, when they are unable to accrete at rates comparable to rising sea level.

Another limitation to the applicability of the CFR classification to other locations is that it does not incorporate freshwater tidal systems. Because watersheds are so small along the southern Delmarva Peninsula, freshwater tidal systems do not occur there and thus were not considered in the study. Unlike coastal forests along the Delmarva Peninsula where state change is driven by both increased hydroperiod and salt intrusion, forest conversion to marsh in tidal freshwater systems, results solely from longer hydroperiods (Orson et al. 1992). For this reason, the CFR classification is not valid in freshwater tidal systems.

Finally, the CFR classification may not be appropriate for determining forest resistance to state change on altered sites. Sites in which forest vegetation has been removed, thinned, burned, or otherwise altered could experience state change more rapidly than unaltered sites because shading to the forest floor is diminished. Increased sunlight penetration allows shrubs and herbaceous species to invade earlier than they normally would. Furthermore, sites that have been hydrologically altered through ditching, diking, impounding or other activity may not drain as this study predicts and so would decrease the certainty of the CFR classification identifying its correct resistance group.

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APPENDIX A. AVERAGE LOW MARSH PERCENT COVER

Average based on three 1m^2 quadrats.

Species/Cover type	Site - Plot Number								
0-1 meters	2-1	2-2	3-1	3-2	5-1	5-2	8-1	8-2	10-1
Spartina alterniflora (>70 cm)						16.7			
Spartina alterniflora (40-70 cm)					30.0		22.5	67.5	
Spartina alterniflora (<40 cm)	34.2	10.8	37.5	47.5		13.3	39.2		0.8
Distichlis spicata	22.5	37.5	0.8	40.0		0.8			
Spartina patens									
Salicornia spp.	10.0	25.8				0.8			0.8
Limonium carolinium		0.8	0.8						
Bare ground	34.2	50.0	61.7	26.7	55.3	41.7	41.7	37.5	44.2
Crab burrow					15.0				10.0
Litter									
Wrack						12.5			53.3
Pothole									
Total	100.8	125.0	100.8	114.2	100.3	85.8	103.3	105.0	109.2
1-3 meters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canopy Cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species/Cover type	Site - Plot Number								
0-1 meters	BSN-2	12T-1	12T-2	13-1	13-2	13H-1	13H-2	17-1	17-2
S. alterniflora (>70 cm)									
S. alterniflora (40-70 cm)			22.5					35.0	0.8
S. alterniflora (<40 cm)	55.8	85.0	35.0	37.5	30.0			12.5	50.0
D. spicata	27.5		0.0		10.0		5.0		
S. patens									
Salicornia spp.			13.3		30.0	27.5	21.7		17.5
L. carolinium									
Bare ground	22.5	15.0	37.5	57.5	41.7	65.8	69.2	57.5	47.5
Crab burrow			0.8			6.7	15.0		
Litter									
Wrack									
Pothole									
Total	105.8	100.0	109.2	95.0	111.7	100.0	110.8	105.0	115.8
1-3 meters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canopy Cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species/Cover type	Site - Plot Number								
0-1 meters	21-2	21B-1	21B-2	22-1	26-1	26-2	27-1	27-2	28-1
S. alterniflora (>70 cm)				85.0					
S. alterniflora (40-70 cm)	30.0		5.0		29.2	35.0	22.5	22.5	
S. alterniflora (<40 cm)		30.0	30.0		29.2	35.0	45.0	12.5	47.5
D. spicata	5.0		30.0					27.5	12.5
S. patens	47.5							5.0	
Salicornia spp.		32.5	1.7						35.8
L. carolinium							5.0		
Bare ground	15.0	47.5	51.7	15.0	5.0	15.0	37.5	37.5	15.0
Crab burrow									
Litter									
Wrack									
Pothole									
Total	97.5	110.0	118.3	100.0	96.7	85.0	110.0	105.0	110.8
1-3 meters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canopy Cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX B. AVERAGE HIGH MARSH PERCENT COVER

Average based on three 1m^2 quadrats.

Species/Cover type	Site - Plot Number						
0-1 meters	2-1	2-2	2-3	2-4	3-1	3-2	3-3
Spartina alterniflora (>70 cm)							
Spartina alterniflora (<40 cm)							
Spartina patens	10.8	17.5	16.7		30.0	29.2	41.7
Distichlis spicata	57.5	17.5	26.7	5.8	53.3	57.5	61.7
Panicum virgatum							
Setaria viridis							
Phragmites australis							
Juncus roemerianus		39.2	29.2	69.2			
Juncus gerardi							
Scirpus sp.						5.0	
Limonium carolinium							
Salicornia spp.							
Atriplex patula							
Iva frutescens	15.0				0.8		
Baccharis halimifolia				16.7			
Erechtites hieracifolia							
Borrichia frutescens							
Juniperus virginiana							
Bare ground	0.8	22.5	12.5	10.0			
Litter							
Wrack	5.0		12.5		5.0		
Pothole						12.5	
Dead shrub			0.8		0.8		
Woody debris							
Total	89.2	96.7	98.3	101.7	90.0	104.2	103.3
1 - 3 m							
Iva frutescens	0.8			16.7			
Total	0.8	0.0	0.0	16.7	0.0	0.0	0.0
Canopy Cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species/Cover type	Site - Plot Number							
0-1 meters	3-4	9-1	9-2	9-3	11B-1	11B-2	12JA-1	12JA-2
S. alterniflora (>70 cm)								
S. alterniflora (<40 cm)								
S. patens	56.7	73.3	95.0	73.3	79.2	5.0		41.7
D. spicata	10.0		5.0	26.7	22.5	79.2	5.0	45.8
P. virgatum								
S. viridis								
P. australis								
J. roemerianus	28.3						61.7	
J. gerardi								
Scirpus sp.								
L. carolinium								
Salicornia spp.								
A. patula								
I. frutescens								
B. halimifolia								
E. hieracifolia								
B. frutescens								
J. virginiana								
Bare ground	5.0						22.5	
Litter								
Wrack	0.8						5.0	
Pothole		30.0			15.0	10.0		
Dead shrub								5.0
Woody debris								
Total	100.8	103.3	100.0	100.0	116.7	94.2	94.2	92.5
1 - 3 m								
I. frutescens								0.8
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Canopy Cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species/Cover type	Site - Plot Number							
0-1 meters	12JB-1	12JB-2	BFF-1	BFF-2	BFF-3	BSN-1	13-1	13H-1
S. alterniflora (>70 cm)								
S. alterniflora (<40 cm)	12.5							
S. patens	29.2			32.5		51.7	57.5	12.5
D. spicata	51.7		67.5	35.0	12.5	51.7	15.0	57.5
P. virgatum								
S. viridis								
P. australis								
J. roemerianus		85.0		28.3	73.3			
J. gerardi							12.5	
Scirpus sp.								
L. carolinium						0.8	6.7	6.7
Salicornia spp.								
A. patula								
I. frutescens							13.3	
B. halimifolia								
E. hieracifolia								
B. frutescens								
J. virginiana								
Bare ground	12.5	15.0						15.0
Litter								
Wrack							5.0	
Pothole			37.5	22.5	15.0			
Dead shrub								
Woody debris								
Total	93.3	100.0	105.0	118.3	100.8	104.2	110.0	91.7
1 - 3 m								
I. frutescens								
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canopy Cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species/Cover type	Site - Plot Number							
0-1 meters	13H-2	17-1	17-2	18-1	21B-1	21B-2	22-1	26-1
S. alterniflora (>70 cm)				1.7				
S. alterniflora (<40 cm)							5.0	15.0
S. patens	27.5	10.0	68.3		28.3		51.7	56.7
D. spicata	50.0	40.0		30.0	45.8	67.5	37.5	
P. virgatum			0.8					
S. viridis								
P. australis								
J. roemerianus								
J. gerardi				47.5				
Scirpus sp.								
L. carolinium	5.8							
Salicornia spp.							0.8	
A. patula							0.8	
I. frutescens		30.0	12.5	0.8	40.0	37.5	0.8	
B. halimifolia								
E. hieracifolia			0.8					
B. frutescens		17.5						
J. virginiana								
Bare ground	10.0				0.8		13.3	
Litter					5.0			
Wrack		5.0		17.5	13.3		0.8	
Pothole								
Dead shrub				5.0				
Woody debris	5.0							
Total	98.3	102.5	82.5	100.8	133.3	105.0	105.8	56.7
1 - 3 m								
I. frutescens		15.0	12.5					
Total	0.0	15.0	12.5	0.0	0.0	0.0	0.0	0.0
Canopy Cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species	Site - Plot Number			
0-1 meters	27-1	27-2	27-3	28-1
S. alterniflora (>70 cm)				
S. alterniflora (<40 cm)				0.8
S. patens	95.0	111.3	55.8	73.3
D. spicata				17.5
P. virgatum				
S. viridis				12.5
P. australis				
J. roemerianus				
J. gerardi				
Scirpus sp.				
L. carolinium			12.5	
Salicornia spp.				
A. patula				5.0
I. frutescens		13.3	17.5	
B. halimifolia				
E. hieracifolia				
B. frutescens				
J. virginiana				
Bare ground				
Litter				
Wrack				
Pothole	0.0	12.5		
Dead shrub				
Woody debris				
Total	95.0	137.2	85.8	108.3
1 - 3 m				
I. frutescens			22.5	
Total	0.0	0.0	22.5	0.0
Canopy Cover	0.0	0.0	0.0	0.0

APPENDIX C. AVERAGE TRANSITION PERCENT COVER

Average based on three 1m2 quadrats.

Species/Cover type	Site - Plot Number					
0 - 1 meters	2-1	3-1	8-1	9-1	10-1	10-2
Spartina alterniflora (>70 cm)			13.3			
Spartina alterniflora (40-70 cm)						
Spartina patens	17.5	10.0	40.8	12.5	10.8	50.0
Distichlis spicata		21.7		5.0		
Panicum virgatum	35.0					
Setaria viridis						
Phragmities australis						
Juncus roemerianus		12.5		0.8		
Juncus gerardi						
Scirpus sp.				0.8		
Limonium carolinium						
Salicornia spp.						
Atriplex patula						
Typha sp.		13.3				
Asclepias incarnata						
Rhus radicans	1.7					
Parthenocissus quinquefolia						
Unidentified graminoid	10.0					
Iva frutescens			12.5			
Baccharis halimifolia	0.8					
Myrica cerifera				40.0		
Juniperus virginiana						
Pinus taeda						
Pinus serotina						
Ilex sp.		0.8				
Bare ground			28.3	47.5		
Crab burrow						
Litter	43.3	12.5	5.0			5.0
Wrack			0.8		73.3	33.3
Pothole						
Dead tree						
Dead shrub		12.5				
Stump	5.0					
Woody debris	15.0	5.0			16.7	

Total	128.3	88.3	100.8	106.7	100.8	88.3

Species/Cover type	Site - Plot Number						
0 - 1 meters	10-3	11-1	11-2	11B-1	12JA-1	12JA-2	12JB-1
S. alterniflora (>70 cm)							
S. alterniflora (40-70 cm)							
S. patens	47.5	10.0		51.7	41.7	30.0	10.0
D. spicata		10.0		21.7	17.5	30.0	17.5
P. virgatum	10.0	0.8	5.0				12.5
S. viridis							5.0
P. australis				24.2			
J. roemerianus				12.5			10.8
J. gerardi							
Scirpus sp.							
L. carolinium							
Salicornia spp.							
A. patula							
Typha sp.							
A. incarnata							
R. radicans							
P. quinquefolia							
Unidentified graminoid							
I. frutescens		30.0	10.8	12.5	34.2	10.0	
B. halimifolia			5.0			5.0	
M. cerifera							
J. virginiana	10.0						5.0
P. taeda							
P. serotina							5.0
Ilex sp.							
Bare ground		39.2					
Crab burrow		0.8					
Litter	10.0		5.0	12.5			5.0
Wrack	16.7	12.5	69.2			5.0	
Pothole							
Dead tree	0.8	12.5			5.0	12.5	
Dead shrub					5.0		
Stump			5.0				5.0
Woody debris	5.0						10.0
Total	100.0	115.8	100.0	135.0	103.3	92.5	85.8

Species/Cover type	Site - Plot Number						
0 - 1 meters	12JB-2	BFF-1	BFF-2	BSN-1	BSN-2	12T-1	13-1
S. alterniflora (>70 cm)							
S. alterniflora (40-70 cm)						5.0	
S. patens	10.0	25.0	12.5	17.5	30.0	25.0	22.5
D. spicata	5.0		12.5	47.5	12.5	25.0	
P. virgatum	1.7	21.7	18.3		30.0		
S. viridis	5.0						
P. australis							
J. roemerianus	33.3	37.5	0.8				0.8
J. gerardi							50.8
Scirpus sp.							
L. carolinium							
Salicornia spp.							
A. patula							
Typha sp.							
A. incarnata							
R. radicans							
P. quinquefolia							
Unidentified graminoid							
I. frutescens				37.5		34.2	30.0
B. halimifolia					17.5	12.5	
M. cerifera	5.0						
J. virginiana		0.8					
P. taeda		5.0	25.0				
P. serotina							
Ilex sp.							
Bare ground						17.5	
Crab burrow						0.8	
Litter	40.0	12.5	47.5				
Wrack							
Pothole							
Dead tree		0.8					
Dead shrub							
Stump	0.8						
Woody debris							
Total	100.8	103.3	116.7	102.5	90.0	120.0	104.2

Species/Cover type	Site - Plot Number						
0 - 1 meters	13-2	13H-1	13H-2	18-1	18-2	21-1	21-2
S. alterniflora (>70 cm)							
S. alterniflora (40-70 cm)							
S. patens	12.5	57.5	22.5	12.5	35.0	5.0	30.0
D. spicata				10.0		12.5	0.8
P. virgatum		10.8	22.5				
S. viridis					22.5		
P. australis							
J. roemerianus	5.0						
J. gerardi				35.0		33.3	
Scirpus sp.							
L. carolinium							10.8
Salicornia spp.							
A. patula							
Typha sp.							
A. incarnata							
R. radicans							
P. quinquefolia					5.0		
Unidentified graminoid							
I. frutescens	22.5	12.5	5.0	45.0	40.0	10.0	25.0
B. halimifolia	10.0		5.0				10.0
M. cerifera							
J. virginiana			5.0				
P. taeda			12.5				
P. serotina							
Ilex sp.							
Bare ground		5.0	12.5		5.0		
Crab burrow							
Litter	45.0		12.5			5.0	10.8
Wrack						1.7	
Pothole						28.3	
Dead tree							
Dead shrub	0.8			5.0			
Stump			5.0				
Woody debris		17.5	5.0				
Total	95.8	103.3	107.5	107.5	107.5	95.8	87.5

Species/Cover type	Site - Plot Number				
0 - 1 meters	21B-1	22-1	22-2	22-3	26-1
S. alterniflora (>70 cm)					
S. alterniflora (40-70 cm)					
S. patens	0.8	73.3	50.0	35.0	17.5
D. spicata	5.0		17.5		5.0
P. virgatum				17.5	5.0
S. viridis					
P. australis					
J. roemerianus					10.0
J. gerardi					
Scirpus sp.					
L. carolinium					
Salicornia spp.			0.8		
A. patula				0.8	
Typha sp.					
A. incarnata				13.3	
R. radicans					
P. quinquefolia					
Unidentified graminoid				10.0	
I. frutescens	67.5	25.8	17.5	5.0	12.5
B. halimifolia				5.0	
M. cerifera					21.7
J. virginiana					
P. taeda					
P. serotina					
Ilex sp.					
Bare ground			22.5		
Crab burrow					
Litter	25.0	0.8			34.2
Wrack	5.0	5.0			
Pothole					
Dead tree					
Dead shrub					
Stump		0.8			
Woody debris					
Total	103.3	105.8	108.3	86.7	105.8

Species	Site - Plot Number						
1 - 3 meters	2-1	3-1	8-1	9-1	10-1	10-2	10-3
Phragmities australis							
Iva frutescens			16.7				
Baccharis halimifolia	4.4	10.0					
Myrica cerifera	17.5	15.0		67.5			
Juniperus virginiana							57.5
Pinus taeda							
Pinus serotina							
Ilex sp.		22.5					
Dead tree						5.0	5.0
Dead shrub							
Total	21.9	47.5	16.7	67.5	0.0	5.0	62.5
Canopy Cover	22.5	0.0	0.0	44.2	0.0	0.0	17.5

Species	Site - Plot Number						
1 - 3 meters	11-1	11-2	11B-1	12JA-1	12JA-2	12JB-1	12JB-2
P. australis			5.0				
I. frutescens				5.0	5.0		
B. halimifolia							
M. cerifera			22.5				12.5
J. virginiana		12.5	5.0			5.0	17.5
P. taeda							
P. serotina						5.0	22.5
Ilex sp.						22.5	
Dead tree	12.5	5.0		17.5	5.0	5.0	
Dead shrub							
Total	12.5	17.5	32.5	22.5	10.0	37.5	52.5
Canopy Cover	0.0	47.5	10.0	5.0	5.0	15.0	38.3

Species	Site - Plot Number								
1 - 3 meters	BFF-1	BFF-2	BSN-1	BSN-2	12T-1	13-1	13-2	13H-1	13H-2
P. australis									
I. frutescens			17.5		57.5	10.0		5.0	
B. halimifolia				5.0			22.5		
M. cerifera		17.5							
J. virginiana	5.0			50.8					
P. taeda	5.0	29.2							12.5
P. serotina									
Ilex sp.									
Dead tree	0.8								
Dead shrub									
Total	10.8	46.7	17.5	55.8	57.5	10.0	22.5	5.0	12.5
Canopy Cover	17.5	30.0	0.0	10.0	5.0	0.0	0.8	0.0	0.0

Species	Site - Plot Number								
1 - 3 meters	18-1	18-2	21-1	21-2	21B-1	22-1	22-2	22-3	26-1
P. australis									
I. frutescens	5.0	33.3	13.3	12.5	29.2	27.5	17.5	13.3	5.0
B. halimifolia				30.0				12.5	13.3
M. cerifera									35.0
J. virginiana								12.5	5.0
P. taeda									
P. serotina									
Ilex sp.									
Dead tree								12.5	
Dead shrub	5.0								
Total	10.0	33.3	13.3	42.5	29.2	27.5	17.5	50.8	58.3
Canopy Cover	0.0	5.0	0.0	0.0	0.0	0.0	0.0	27.5	33.3

APPENDIX D. AVERAGE FOREST PERCENT COVER

Average based on three 1m^2 quadrats.

Species/Cover type	Site - Plot Number					
0 -1 meters	2-1	2-2	2-3	3-1	3-2	3-3
Distichlis spicata						
Panicum virgatum	10.0					
Setaria viridis						
Juncus roemerianus						
Limonium carolinium						
Atriplex patula						
Asclepias incarnata						
Hydrocotyle sp.						
Rhus radicans				0.8		
Bignonia capreolata						
Parthenocissus quinquefolia						
Vitis sp.					0.8	
Smilax bona-nox	1.7	29.2	18.3		10.0	0.8
Smilax rotundifolia						
Unidentified graminoid	1.7			0.8		
Iva frutescens						
Myrica cerifera	5.0		5.0	5.0		
Erechtites hieracifolia						
Juniperus virginiana						
Pinus taeda						
Pinus serotina						
Prunus serotina					0.8	
Ilex opaca						
Nyssa sylvatica						
Celtis occidentalis						
Liquidambar styraciflua					5.0	
Persea borbonia			0.8	13.3		10.8
Aralia spinosa						
Ligustrum sp.		1.7	0.8			
Quercus phellos						
Bare ground						
Crab burrow						
Litter	73.3	53.3	73.3	77.5	67.5	85.0
Wrack						
Dead tree						
Stump						

Woody debris	10.0	10.8	13.3	12.5	5.8	15.0
Total	101.7	95.0	111.7	110.0	90.0	111.7

Species/Cover type	Site - Plot Number						
0 -1 meters	5-1	5-2	5-3	8-1	9-1	9-2	9-3
D. spicata							
P. virgatum							5.0
S. viridis							5.0
J. roemerianus							
L. carolinium							
A. patula							
A. incarnata			5.0	12.5			
Hydrocotyle sp.							5.0
R. radicans	15.0	10.0				0.8	5.0
B. capreolata	10.0	15.0	37.5				
P. quinquefolia	0.8		5.0				
Vitis sp.			5.0				
S. bona-nox	15.0	12.5		17.5			
S. rotundifolia		5.0					
Unidentified graminoid							5.0
I. frutescens							
M. cerifera					17.5		
E. hieracifolia				29.2			
J. virginiana							
P. taeda							
P. serotina							
P. serotina							
I. opaca		5.0					
N. sylvatica						0.8	
C. occidentalis		5.0					
L. styraciflua							
P. borbonia							
A. spinosa	5.0						
Ligustrum sp.							
Q. phellos							
Bare ground				12.5			22.5
Crab burrow							
Litter	61.7	47.5	57.5	22.5	51.7	83.3	45.0
Wrack				10.0			
Dead tree							5.0
Stump							
Woody debris		5.0	10.0		34.2	18.3	10.0
Total	107.5	105.0	120.0	104.2	103.3	103.3	107.5

Species/Cover type	Site - Plot Number						
0 -1 meters	11-1	12JA-1	BFF-1	BFF-2	BFF-3	BSN-1	BSN-2
D. spicata				0.8			
P. virgatum	0.8			13.3	5.0		5.0
S. viridis							
J. roemerianus					5.0		
L. carolinium							
A. patula							
A. incarnata							
Hydrocotyle sp.							
R. radicans			2.5	0.8	0.8	22.5	5.8
B. capreolata							
P. quinquefolia							
Vitis sp.							
S. bona-nox							10.0
S. rotundifolia							
Unidentified graminoid	30.0						
I. frutescens							
M. cerifera		5.0	5.0	12.5			
E. hieracifolia							
J. virginiana				0.8			
P. taeda			16.7		5.0		
P. serotina		5.0					
P. serotina							
I. opaca							
N. sylvatica							
C. occidentalis							
L. styraciflua							
P. borbonia							
A. spinosa							
Ligustrum sp.							
Q. phellos							
Bare ground							
Crab burrow	47.5						
Litter	37.5	73.3	63.3	73.3	85.0	63.3	79.2
Wrack	1.7						
Dead tree							
Stump							
Woody debris		15.0	22.5	5.0	5.0	21.7	
Total	117.5	98.3	110.0	106.7	105.8	107.5	100.0

Species/Cover type	Site - Plot Number						
0 -1 meters	BSN-3	12T-1	13-1	13-2	21-1	21-2	21-3
D. spicata							
P. virgatum				35.8			
S. viridis							
J. roemerianus							
L. carolinium					12.5		
A. patula							
A. incarnata							
Hydrocotyle sp.							
R. radicans	5.0		6.7	10.0	5.8	5.8	0.8
B. capreolata	0.8		22.5	15.0		5.0	15.0
P. quinquefolia	0.8				0.8	0.8	
Vitis sp.							
S. bona-nox	0.8	0.8	1.7			0.8	
S. rotundifolia							
Unidentified graminoid							
I. frutescens		5.0					
M. cerifera					12.5		
E. hieracifolia							
J. virginiana		5.0			16.7		
P. taeda							
P. serotina							
P. serotina							
I. opaca							
N. sylvatica							
C. occidentalis			0.8				
L. styraciflua			12.5				
P. borbonia							
A. spinosa							
Ligustrum sp.							
Q. phellos						5.0	
Bare ground							
Crab burrow							
Litter	73.3	83.3	51.7	34.2	50.0	73.3	67.5
Wrack							
Dead tree	0.8						
Stump							
Woody debris	17.5	5.0	22.5	12.5	5.0	17.5	22.5
Total	99.2	99.2	118.3	107.5	103.3	108.3	105.8

Species/Cover type	Site - Plot Number				
0 -1 meters	22-1	22-2	26-1	26-2	26-3
D. spicata					
P. virgatum					
S. viridis					
J. roemerianus					
L. carolinium					
A. patula	5.0	5.0			
A. incarnata		0.8			
Hydrocotyle sp.					
R. radicans	0.8	5.8	1.7	5.0	5.0
B. capreolata		0.8			
P. quinquefolia					
Vitis sp.					
S. bona-nox					
S. rotundifolia					
Unidentified graminoid					
I. frutescens					
M. cerifera	22.5		0.8	0.8	
E. hieracifolia					
J. virginiana	5.0		12.5		
P. taeda			5.0		29.2
P. serotina					
P. serotina					
I. opaca					
N. sylvatica					
C. occidentalis					
L. styraciflua					
P. borbonia					
A. spinosa			0.8		
Ligustrum sp.					
Q. phellos					
Bare ground					
Crab burrow					
Litter	57.5	73.3	73.3	79.2	61.7
Wrack					
Dead tree					
Stump					
Woody debris	25.0	15.0			
Total	115.8	100.8	94.2	85.0	95.8

Species	Site - Plot Number						
1-3 meters	2-1	2-2	2-3	3-1	3-2	3-3	5-1
Rhus radicans							
Bignonia capreolata							
Vitis sp.				5.0		5.0	
Smilax bona-nox							
Smilax rotundifolia							
Iva frutescens							
Myrica cerifera	5.8			34.2	5.0		
Juniperus virginiana							
Pinus taeda	0.8						
Pinus serotina							
Prunus serotina							
Ilex opaca			5.0				
Acer rubrum				0.8	5.0	5.0	
Nyssa sylvatica							
Celtis occidentalis							
Liquidambar styraciflua							
Persea borbonia					5.0	5.0	
Aralia spinosa							
Quercus phellos							
Liriodendron tulipifera							
Dead vines	0.8						
Dead tree							
Total	7.5	0.0	100.0	40.0	15.0	15.0	0.0
Canopy Cover	61.7	61.7	69.2	40.8	47.5	55.8	30.0

Species	Site - Plot Number							
1-3 meters	5-2	5-3	8-1	9-1	9-2	9-3	11-1	12JB-1
R. radicans						5.0		
B. capreolata								
Vitis sp.								
S. bonanox			17.5					
S. rotundifolia								
I. frutescens								
M. cerifera				25.0				0.8
J. virginiana				10.0			18.3	5.0
P. taeda								
Pinus serotina								5.0
Prunus serotina								
I. opaca	22.5							
A. rubrum								
N. sylvatica				5.0	12.5			
C. occidentalis		12.5						
L. styraciflua		22.5						
P. borbonia								
A. spinosa	12.5							
Q. phellos								
L. tulipifera	12.5							
Dead vines								
Dead tree		5.0						
Total	47.5	40.0	17.5	40.0	12.5	5.0	18.3	5.0
Canopy Cover	63.3	77.5	61.7	67.5	73.3	85.0	45.0	67.5

Species	Site - Plot Number							
1-3 meters	BFF-1	BFF-2	BFF-3	BSN-1	BSN-2	BSN-3	12T-1	13-1
R. radicans								
B. capreolata						12.5		5.0
Vitis sp.								
S. bonanox								
S. rotundifolia						29.2		
I. frutescens								
M. cerifera	22.5	12.5					5.0	
J. virginiana		5.0		12.5			45.0	
P. taeda	16.7							
Pinus serotina								
Prunus serotina				5.0	12.5	16.7	12.5	
I. opaca								
A. rubrum								
N. sylvatica								
C. occidentalis								
L. styraciflua								12.5
P. borbonia								
A. spinosa								
Q. phellos								
L. tulipifera								
Dead vines								
Dead tree					5.0			
Total	39.2	17.5	0.0	17.5	17.5	58.3	62.5	17.5
Canopy Cover	61.7	61.7	50.0	57.5	22.5	57.5	55.8	79.2

Species	Site - Plot Number								
1-3 meters	13-2	21-1	21-2	21-3	22-1	22-2	26-1	26-2	26-3
R. radicans									
B. capreolata									
Vitis sp.									
S. bonanox				10.0					
S. rotundifolia									
I. frutescens		5.0							
M. cerifera		5.0			22.5				
J. virginiana		17.5			27.5	0.8			
P. taeda		5.0							
Pinus serotina									
Prunus serotina									
I. opaca				22.5					
A. rubrum									
N. sylvatica									
C. occidentalis	28.3					10.0			
L. styraciflua	22.5								
P. borbonia									
A. spinosa									
Q. phellos			22.5						
L. tulipifera									
Dead vines									
Dead tree									
Total	50.8	32.5	22.5	32.5	50.0	10.8	0.0	0.0	0.0
Canopy Cover	32.5	45.8	41.7	73.3	61.7	73.3	73.3	41.7	67.5

APPENDIX E. HIGH MARSH WOODY SPECIES DENSITY

There was no basal area in the high marsh.

Species	Site - Plot Number										
Stems/ha	2-1	2-2	2-3	2-4	3-1	3-2	3-3	3-4	5-1	5-2	9-1
Iva frutescens	2653		354	442	531						
Baccharis halimifolia				1592							
Juniperus virginiana											
Total	2653	0	354	2034	531	0	0	0	0	0	0

Species	Site - Plot Number										
Stems/ha	9-2	9-3	11B-1	11B-2	12JA-1	12JA-2	12JB-1	12JB-2	BFF-1	BFF-2	BFF-3
I. frutescens	265				1238	2387			265		
B. halimifolia											
J. virginiana						88					
Total	265	0	0	0	1238	2476	0	0	265	0	0

Species	Site - Plot Number										
Stems/ha	BSN-1	13-1	13H-1	13H-2	17-1	17-2	18-1	21B-1	21B-2	22-1	26-1
I. frutescens		973		1326	1655	764	398	2122	1680		
B. halimifolia						255					
J. virginiana											
Total	0	973	0	1326	1655	1019	398	2122	1680	0	0

Species	Site - Plot Number			
Stems/ha	27-1	27-2	27-3	28-1
I. frutescens	105		2315	

B. halimifolia			1158	
J. virginiana				
Total	105	0	3473	0

APPENDIX F. TRANSITION WOODY SPECIES DENSITY AND BASAL AREA

Species	Site - Plot Number									
Stems/ha	2-1	3-1	8-1	9-1	10-1	10-2	10-3	11-1	11-2	11B-1	12JA-1
Iva frutescens							88	973		1768	1326
Baccharis halimifolia	707			88	177	531	88	88			619
Myrica cerifera	1945			619			88				
Juniperus virginiana					619	1149	1238	177	354	177	
Pinus taeda							88			177	
Total	2653	0	0	707	796	1680	1592	1238	354	2122	1945
m^2/ha											
Iva frutescens											
Baccharis halimifolia											
Myrica cerifera											
Juniperus virginiana					2.2		5.2	1.4	6.6		
Pinus taeda							1.1			5.7	
Total	0.0	0.0	0.0	0.0	2.2	0.0	6.3	1.4	6.6	5.7	0.0

Species	Site - Plot Number											
Stems/ha	12JA-2	12JB-1	12JB-2	BFF-1	BFF-2	BSN-1	BSN-2	12T-1	13T-1	13T-2	13H-1	13H-2
I. frutescens	707	177				3006	354	3537	3272	1782	796	884
B. halimifolia	354	354				177	265	177		1655	619	531
M. cerifera			265	354	1680							
J. virginiana	88	2211	1503	1149	265		354	177			177	531
P. taeda		177	707	2211	2653							707
Total	1149	2918	2476	3714	4598	3183	973	3890	3272	3438	1592	2653
m^2/ha												
I. frutescens												
B. halimifolia												
M. cerifera												
J. virginiana		1.0	3.9		2.3		1.9					
P. taeda			7.6	1.0	12.8							
Total	0.0	1.0	11.5	1.0	15.1	0.0	1.9	0.0	0.0	0.0	0.0	0.0

Species	Site - Plot Number								
Stems/ha	18-1	18-2	21-1	21-2	21B-1	22-1	22-2	22-3	26-1
I. frutescens	3890	2829	4420	1052	4421	4421	1768	1326	177
B. halimifolia		884		1368		88		619	884
M. cerifera				210					884
J. virginiana				526				177	177
P. taeda									
Total	3890	3714	4420	3157	4421	4509	1768	2122	2122
m^2/ha									
I. frutescens									
B. halimifolia									
M. cerifera									
J. virginiana								2.9	
P. taeda									
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0

APPENDIX G. FOREST WOODY SPECIES DENSITY AND BASAL AREA

Species	Site - Plot Number						
Stems/ha	2-1	2-2	2-3	3-1	3-2	3-3	5-1
Vaccinium corymbosum							
Baccharis halimifolia							
Myrica cerifera	973		88	2829	354	177	
Juniperus virginiana							
Pinus taeda	442	619			707	796	265
Prunus serotina	177		265	354		177	
Ilex opaca			265				
Acer rubrum				177	88	265	
Nyssa sylvatica			88		442	707	88
Celtis occidentalis						177	88
Liquidambar styraciflua			88		177		177
Persea borbonia				177	442	1061	
Aralia spinosa							265
Quercus falcata			88				
Quercus phellos							
Liriodendron tulipifera							88
Magnolia virginiana							
Total	1592	619	884	3537	2211	3360	973
m^2/ha							
Juniperus virginiana							
Pinus taeda	13.3	15.1			19.6	22.0	8.8
Prunus serotina			3.6				
Ilex opaca							
Nyssa sylvatica			1.9		4.6	3.5	1.2
Celtis occidentalis						1.2	
Liquidambar styraciflua			3.5		2.1		6.7
Persea borbonia					1.2		
Quercus falcata			2.4				
Liriodendron tulipifera							4.4
Total	13.3	15.1	11.4	0.0	27.5	26.7	21.2

Species	Site - Plot Number							
Stems/ha	5-2	5-3	8-1	9-1	9-2	9-3	11-1	12JB-1
V. corymbosum								
B. halimifolia								
M. cerifera				1768	265			619
J. virginiana				354			1061	1768
P. taeda				619	531	265		1149
P. serotina								
I. opaca	88	88	88					
A. rubrum								
N. sylvatica				1503	884	531		
C. occidentalis			354					
L. styraciflua		88				265		
P. borbonia								
A. spinosa	1061							
Q. falcata								
Q. phellos								
L. tulipifera	265	177						
M. virginiana					177			
Total	1415	354	442	4244	1857	1061	1061	3537
m^2/ha								
J. virginiana				1.8			9.3	3.2
P. taeda				17.4	18.4	9.2		13.2
P. serotina								
I. opaca								
N. sylvatica				17.7	10.6	12.1		
C. occidentalis			7.3					
L. styraciflua		3.2						
P. borbonia								
Q. falcata								
L. tulipifera	15.7	5.7						
Total	15.7	8.8	7.3	36.9	29.0	21.3	9.3	16.4

Species	Site - Plot Number							
Stems/ha	BFF-1	BFF-2	BFF-3	BSN-1	BSN-2	BSN-3	12T-1	13-1
V. corymbosum								
B. halimifolia							177	
M. cerifera	1149	796		442				88
J. virginiana	354	177		265	88	442	1592	88
P. taeda	2122	1238	707	1415	88	88	177	531
P. serotina				88	177	531	531	
I. opaca	88	354	88			88		
A. rubrum								
N. sylvatica								
C. occidentalis								884
L. styraciflua			88					354
P. borbonia								
A. spinosa								
Q. falcata								
Q. phellos								
L. tulipifera								
M. virginiana								
Total	3714	2564	884	2211	354	1149	2476	1945
m^2/ha								
J. virginiana		1.1		1.9		6.9	6.2	1.1
P. taeda	30.0	21.9	14.1	15.2	4.3	4.6	2.1	20.9
P. serotina					4.5	0.9	5.3	
I. opaca	0.9					1.6		
N. sylvatica								
C. occidentalis								2.6
L. styraciflua								5.3
P. borbonia								
Q. falcata								
L. tulipifera								
Total	30.9	23.1	14.1	17.1	8.8	14.0	13.6	30.0

Species	Site - Plot Number							
Stems/ha	13-2	21-1	21-2	21-3	22-1	22-2	26-1	26-2
V. corymbosum								
B. halimifolia		177	265					
M. cerifera		354			88		1415	88
J. virginiana		177			265		796	88
P. taeda		177	177	177			442	354
P. serotina			88	88			88	
I. opaca		442	796	796		531		
A. rubrum								
N. sylvatica			88				88	531
C. occidentalis	707				354	177		
L. styraciflua								177
P. borbonia								
A. spinosa				177				442
Q. falcata								
Q. phellos			88					
L. tulipifera								
M. virginiana							88	
Total	707	1326	1503	1238	707	707	2918	1680
m^2/ha								
J. virginiana		3.9			1.0		10.1	
P. taeda		5.8	7.1	8.4			11.3	13.9
P. serotina				1.5				
I. opaca		4.2	5.3	5.7				
N. sylvatica			2.0					7.8
C. occidentalis	8.0				6.4	5.7		
L. styraciflua								
P. borbonia								
Q. falcata								
L. tulipifera								
Total	8.0	14.0	14.4	15.6	7.3	5.7	21.4	21.7

Species	
Stems/ha	26-3
V. corymbosum	
B. halimifolia	
M. cerifera	
J. virginiana	
P. taeda	265
P. serotina	265
I. opaca	88
A. rubrum	
N. sylvatica	354
C. occidentalis	
L. styraciflua	
P. borbonia	
A. spinosa	619
Q. falcata	
Q. phellos	
L. tulipifera	
M. virginiana	
Total	1592
m^2/ha	
J. virginiana	
P. taeda	9.4
P. serotina	4.9
I. opaca	
N. sylvatica	1.1
C. occidentalis	
L. styraciflua	
P. borbonia	
Q. falcata	
L. tulipifera	
Total	15.4

APPENDIX H. DENSITY OF LOW MARSH DEAD WOODY VEGETATION COMPONENTS

Component	Site - Plot Number											
Stems/ha	2-1	2-2	3-1	3-2	5-1	5-2	8-1	8-2	10-1	12JA-1	12JA-2	BSN-1
Stump	88	88							177	177	177	
Dead shrub(<1m)									88		88	
Dead shrub(>1m)									0			
Dead trees									88			
Total	88	88	0	0	0	0	0	0	354	177	265	0

Component	Site - Plot Number											
Stems/ha	BSN-2	12T-1	12T-2	13-1	13-2	13H-1	13H-2	17-1	17-2	18-1	18-2	21-1
Stump	265		88		177							
Dead shrub(<1m)												
Dead shrub(>1m)												
Dead trees	88											
Total	354	0	88	0	177	0	0	0	0	0	0	0

Component	Site - Plot Number									
Stems/ha	21-2	21B-1	21B-2	22-1	26-1	26-2	27-1	27-2	28-2	28-2
Stump										
Dead shrub(<1m)										
Dead shrub(>1m)										
Dead trees										
Total	0	0	0	0	0	0	0	0	0	0

APPENDIX I. DENSITY OF HIGH MARSH DEAD WOODY VEGETATION COMPONENTS

Component	Site - Plot Number											
Stems/ha	2-1	2-2	2-3	2-4	3-1	3-2	3-3	3-4	9-1	9-2	9-3	11B-1
Stump				88								
Dead shrub(<1m)		177	265		88		88			88		
Dead shrub(>1m)		88	88		177							
Dead trees		88										
Total	0	354	354	88	265	0	88	0	0	88	0	0

Component	Site - Plot Number											
Stems/ha	11B-2	12JA-1	12JA-2	12JB-1	12JB-2	BFF-1	BFF-2	BSN-1	13-1	13H-1	13H-2	17-1
Stump		707	707				88				619	
Dead shrub(<1m)		884	619	88		88			88	265	442	382
Dead shrub(>1m)		707	265									
Dead trees		177	88			88					619	
Total	0	2476	1680	88	0	177	88	0	88	265	1680	382

Component	Site - Plot Number									
Stems/ha	17-2	18-1	21B-1	21B-2	22-2	26-1	27-1	27-2	27-3	28-1
Stump	127									
Dead shrub(<1m)	382	398	354	1592						
Dead shrub(>1m)						354	105	1789		
Dead trees										
Total	509	398	354	1592	0	354	105	1789	0	0

APPENDIX J. DENSITY OF TRANSITION DEAD WOODY VEGETATION COMPONENTS

Component	Site - Plot Number											
Stems/ha	2-1	3-1	9-1	10-1	10-2	10-3	11-1	11-2	11B-1	12JA-1	12JA-2	12JB-1
Stump	177				177	177		177		177	177	707
Dead shrub(<1m)										88	265	
Dead shrub(>1m)				265						88		
Dead trees				619	442	265	619	619	177	1945	707	531
Total	177	0	0	884	619	442	619	796	177	2299	1149	1238

Component	Site - Plot Number											
Stems/ha	12JB-2	BFF-1	BFF-2	BSN-1	BSN-2	12T-1	13-1	13-2	13H-1	13H-2	18-1	18-2
Stump	707	707	354	531	442	707	88	265	88	531		
Dead shrub(<1m)				88		177			88	354	177	
Dead shrub(>1m)				442		177				177	442	177
Dead trees	88	88	177						531			
Total	796	796	531	1061	442	1061	88	265	707	1061	619	177

Component	Site - Plot Number						
Stems/ha	21-1	21-2	21B-1	22-1	22-2	22-3	26-1
Stump		105		88		88	177
Dead shrub(<1m)	316	526			619		
Dead shrub(>1m)	421			265	1857		
Dead trees	105		88			88	177
Total	842	631	88	354	2476	177	354

APPENDIX K. DENSITY OF FOREST DEAD WOODY VEGETATION COMPONENTS

Component	Site - Plot Number										
Stems/ha	2-1	2-2	2-3	3-1	3-2	3-3	5-1	5-2	5-3	8-1	9-1
Stump	177	265	88			354	177		88		354
Dead shrub(<1m)											
Dead shrub(>1m)											
Dead trees		354		177	88	265			354	88	177
Total	177	619	88	177	88	619	177	0	442	88	531

Component	Site - Plot Number										
Stems/ha	9-2	9-3	11-1	12BJ-1	BFF-1	BFF-2	BFF-3	BSN-1	BSN-2	BSN-3	12T-1
Stump	619	707	442	1326	177	442	707	442	88	265	707
Dead shrub(<1m)											
Dead shrub(>1m)											
Dead trees	265			354	88	88	265	177	177	442	177
Total	884	707	88	1680	265	531	973	619	265	707	884

Component	Site - Plot Number									
Stems/ha	13-1	13-2	21-1	21-2	21-3	22-1	22-2	26-1	26-2	26-3
Stump	265		177	265	354	88	354	177	177	88
Dead shrub(<1m)										
Dead shrub(>1m)										
Dead trees	88	177	177	354	354	88	354	88	177	265
Total	354	177	354	619	707	177	707	265	354	354

APPENDIX L. DEPTH (CM) OF ORGANIC RICH HORIZON BY SAMPLE PLOT

I did not auger below 100 cm. Therefore, sites reported as 100 cm depth may actually have organic rich soils at greater depths. L = low marsh, H = high marsh, T = transition, F = forest

	Zone- Plot Number											
Site	L-1	L-2	H-1	H-2	H-3	H-4	T-1	T-2	T-3	F-1	F-2	F-3
2	0	0	16	15	8	10	6			5	6	6
3	100	100	100	100	75	40	5			6	5	5
5	100	100								0	0	0
8	15	0					0			0		
9			30	45	30		5			5	5	2
10	0						2	2	2			
11							0	0		0		
11B			50	40			5					
12JA	0	0	0	0	9	13						
12JB			4	25			8	6		5		
BFF			10	10			10	10		3	3	4
BSN	18	5	10				0	0		6	2	1
12T	10	0					0			0		
13	5	10	5				10	6		0	0	
13H	0	0	0	0			4	3				
17	100	35	0	4								
18	70	35	20				8	0				
21	100	56					40	4		2	0	2
21B	80	20	0	0			0					
22	60		30				0	0	0	0	0	

26	90	90	15			10	5	3	0
27	100	100	100	100	100				
28	35	45	0						

APPENDIX M. PERCENT SOIL ORGANIC MATTER BY ZONE

Subsurface is the first 10 cm of the second deepest horizon.

Site	0-10 cm					Subsurface			
	Low marsh	High marsh	Transition	Forest		Low marsh	High marsh	Transition	Forest
2	7.9	21.7	45.7	60.0		2.9	5.8	7.6	3.1
3	21.9	24.6	14.9	30.3		30.2	18.8	3.0	6.7
5	18.1			1.9		20.6			2.2
8	6.7		1.8	5.0		2.3		2.0	3.0
9		54.3	15.0	9.3			10.8	2.9	4.1
10	11.7		4.5			1.9		2.2	
11			7.5	20.7				3.6	5.8
11B		59.5	26.0				10.2	5.2	
12JA	8.5					7.8			
12JB		47.6	28.9	62.7			24.8	8.1	11.4
BFF		33.7	11.0	24.2			15.7	3.6	4.3
BSN	30.9	15.1	5.1	13.1		2.2	5.8	1.9	3.7
12T	9.8		13.3	21.3		3.0		6.2	3.0
13	7.8	12.2	11.1	17.5		4.5	5.1	3.4	2.3
13H	3.1	9.3	10.9			3.0	3.4	2.6	
17	26.4	2.5				4.4	1.9		
18	31.8	42.0	5.1			4.8	6.0	2.1	
21	47.3		17.5	6.5		41.2		3.9	2.3
21B	42.8	8.6	5.8			9.1	1.9	1.7	
22	24.0	15.8	9.6	6.6		16.4	13.4	2.8	2.7
26	45.5	61.9	18.2	1.2		38.7	4.9	7.5	3.1
27	32.9	50.2				33.6	47.8		

28	16.8	5.4			13.0	1.9

APPENDIX N. SOIL SALINITY (PPT) BY ZONE

Subsurface is the first 10 cm of the second deepest horizon.

Site	0-10 cm					Subsurface			
	Low marsh	High marsh	Transition	Forest		Low marsh	High marsh	Transition	Forest
2	15.0	10.2	1.5	0.4		6.3	6.1	0.7	0.2
3	20.0	23.6	1.6	0.3		21.2	8.0	0.4	0.3
5	19.5			0.1		14.9			0.1
8	12.4		0.3	0.1		7.9		0.3	0.1
9		9.2	2.7	0.1			6.6	0.7	0.2
10	15.8		1.4			2.4		1.0	
11			2.6	4.7				0.9	1.3
11B		21.1	2.7				7.3	1.0	
12JA	11.8					4.7			
12JB		8.8	4.6	1.7			7.2	1.1	1.2
BFF		12.4	1.1	0.8			4.2	0.6	0.4
BSN	18.1	14.6	2.0	0.1		2.7	6.0	1.0	0.2
12T	11.5		4.4	0.3		7.3		1.2	0.2
13	12.9	6.2	1.9	0.1		5.9	4.0	1.3	0.1
13H	5.6	7.1	0.8			3.9	2.5	0.6	
17	36.2	0.9				8.2	0.8		
18	35.2	21.3	2.1			1.5	5.7	1.3	
21	18.3		7.8	0.2		17.4		1.7	0.3
21B	16.3	3.3	2.4			6.8	5.8	2.4	
22	19.2	14.4	8.2	0.3		14.4	11.3	0.8	0.6
26	19.1	14.6	2.7	0.6		21.7	2.9	0.4	0.1
27	21.9	8.7				29.2	16.9		

28	16.7	2.6		19.1	1.2

APPENDIX O. ELEVATION (M) ABOVE MEAN SEA LEVEL FOR SAMPLE PLOTS

Asterisk * indicates sites whose elevations were estimated L= low marsh, H = high marsh, T= transition, F = forest

	Zone- Plot Number											
Site	L-1	L-2	H-1	H-2	H-3	H-4	T-1	T-2	T-3	F-1	F-2	F-3
2	0.481	0.531	0.876	0.851	0.796	0.856	0.993			1.168	1.283	1.378
3	0.600	0.700	0.895	0.855	0.870	0.890	0.905			1.190	1.365	1.500
5	0.621	0.656								1.546	1.981	2.471
8	0.565	0.665					1.035			1.745		
9*			0.907	1.012	0.962		0.877			0.972	0.967	1.127
10		0.642					1.222	1.242	1.327			
11*							1.301	1.301		1.381		
11B			0.859	0.844			1.004					
12JA	0.849	0.899	1.004	1.114			1.109	1.179				
12JB			0.934	0.954			1.204	1.084		1.279		
BFF			0.976	1.021			1.106	1.231		1.161	1.196	1.281
BSN	0.834	0.809	0.944				1.044	1.189		1.409	1.409	1.549
12TNC	0.664	0.759					1.199			1.334		
13	0.757	0.792	0.992				1.142	1.272		1.482	1.842	
13H	0.883	0.943	1.013	1.023			1.238	1.398		1.428		
17*	0.429	0.409	0.759	0.924						1.164		
18*												
21*	0.768	0.898					0.928	1.108		1.393	1.543	1.518
21B*	0.726	0.801	0.911	0.956			1.021			1.171		
22*		0.546	0.911				1.326	1.151	1.366	1.536	1.701	
26*	0.782	0.837	0.852				0.877			1.447	1.647	2.047
27*	0.708	0.708	0.783	0.823	0.878					1.698		

28*	0.672 0.657	0.787		1.122

APPENDIX P. ZONE WIDTH (M) MEASURED IN THE FIELD

Blank cells represent zones not sampled, and cells with zero represent missing zones.

Site	Zone			
	Low marsh	High marsh	Transition	Forest
2	24	100	7	36
3	24	176	4	36
5	24	0	0	36
8	24	0	3	12
9		157	4	36
10	12	0	55	
11		0	20	12
11B		72	8	
12JA	24	6	26	
12JB		202	42	12
BFF		99	30	36
BSN	24	8	21	36
12T	24	0	6	9
13	24	14	20	18
13H	24	32	18	
17	24	20	0	
18	24	4	18	
21	24	0	22	36
21B	24	33	12	
22	12	8	60	18
26	24	6	6	36
27	24	33	0	
28	24	6	0	

APPENDIX Q. COASTAL FOREST RESISTANCE CLASSIFICATION WORKSHEETS

STEPS
FOR DETERMINATION OF FOREST RESISTANCE TO STATE CHANGE

LOCATE SITE
ON SOIL SURVEY

CHOOSE LEVEL
OF PRECISION DESIRED

<u>LESS PRECISE</u>
Forest resistance classification only:
Low, Intermediate, or High

FOLLOW FLOW CHARTS
IN KEY 1
BEGINNING WITH KEY 1A
to determine forest resistance group.
You may be sent to key 2 if your site does not match one in this study

<u>MORE PRECISE</u>
Score indicating position within the forest resistance group: Low, Intermediate, or High

FOLLOW STEPS
IN KEY 2
to determine score and forest resistance group

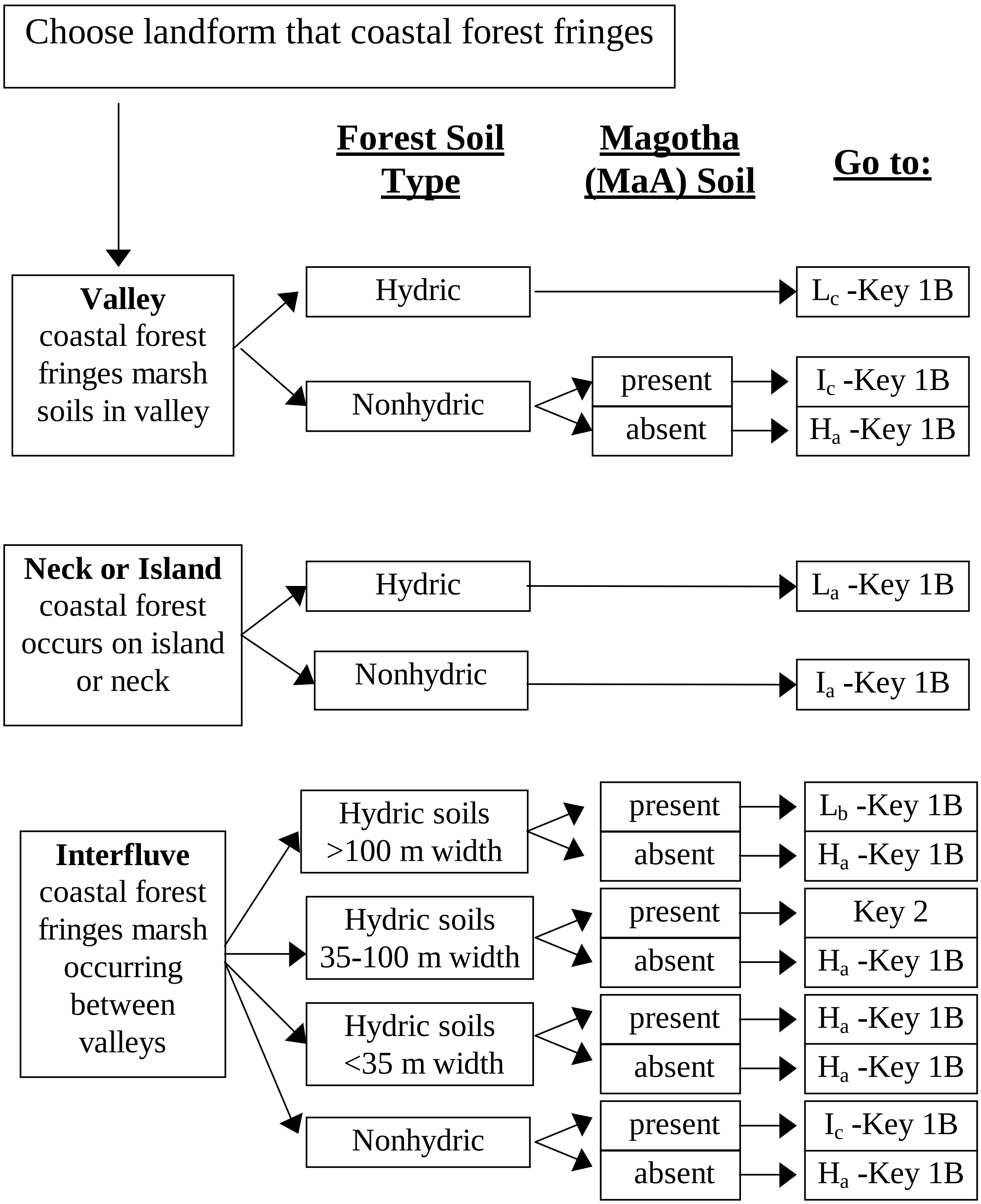
<u>INTERPRETATION OF FOREST RESISTANCE CLASSIFICATION</u>

LOW: forest is very likely to begin conversion to marsh with a 15 cm rise in sea level.

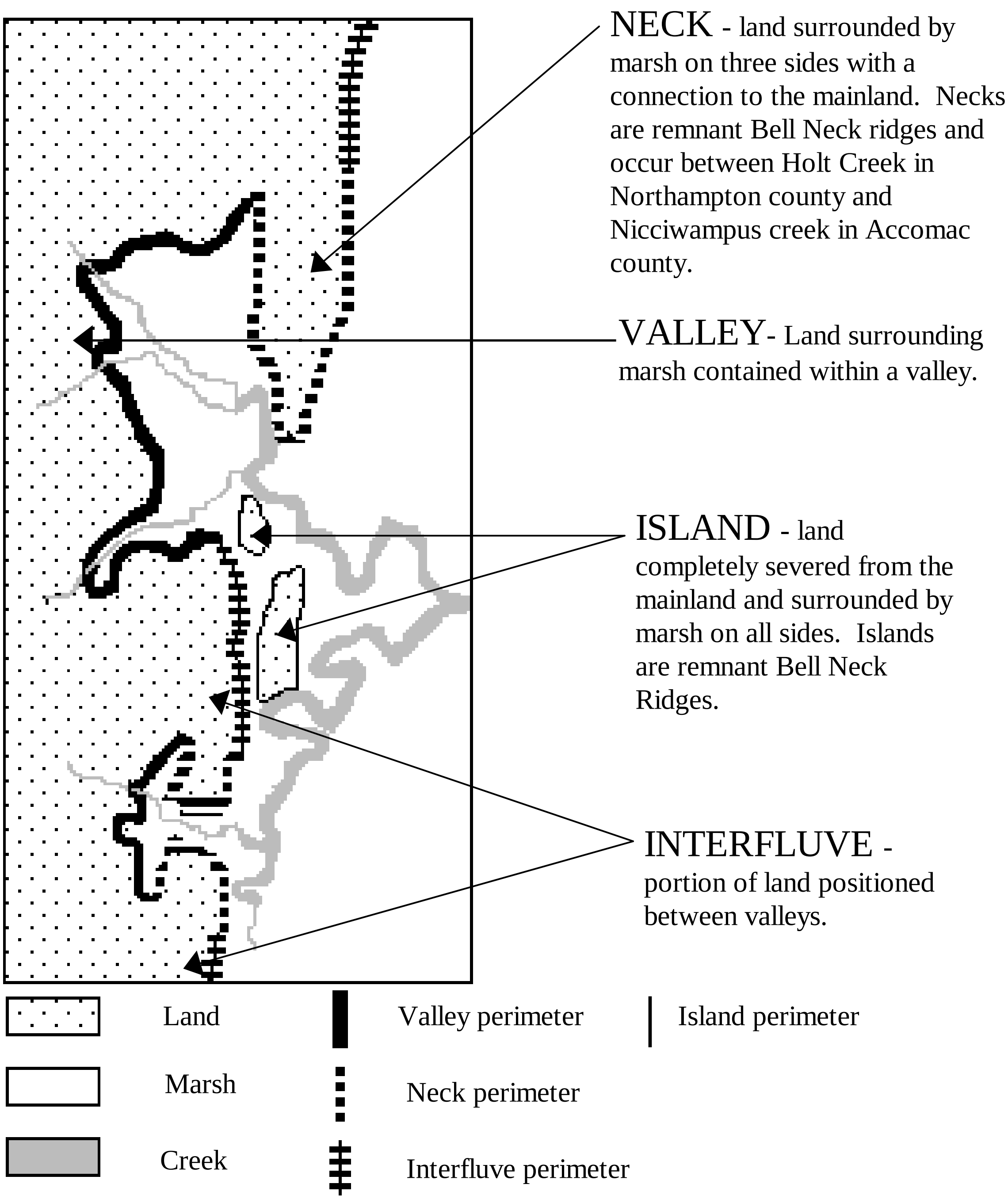
INTERMEDIATE: forest is somewhat likely to begin conversion to marsh with a 15 cm rise in sea level.

HIGH: forest is very unlikely to begin conversion to marsh with a 15 cm rise in sea level.

Key 1A. Map indicators. Refer to Key 1A Supplement 1 and 2 for landform descriptions and a list of forest (hydric and nonhydric) and marsh soil series. Magotha (MaA) soils occur in the high marsh and transition zones. Width of forest soil is measured perpindicular to the coastline.



Key 1A. Supplement 1. LANDFORMS



* The boundary between the valley mouth and interfluve is not always distinct. When in question, assume valley when forest soils are hydric. If forest soils are nonhydric then either landform will give the same classification results.

Key 1A. Supplement 2. SOIL SERIES

SEASIDE SOIL SERIES OF NORTH HAMPTON AND ACCOMAC COUNTIES

FOREST SOILS Nonhydric	**FOREST SOILS Hydric**	**MARSH SOILS Hydric**
Assateague (Atd) Bojac (BkA, BoA, Bhb) Fisherman (FhB) Molena (MoA) Munden (MuA) Seabrook (SeA) Udorthents, Udipsamments (UpD)	Arapahoe (ArA or AhA) Camocca (CaA) Dragston (DrA) Nimmo (NmA) Polawana (PoA)	Chincoteague (ChA) Magotha (MaA)

Key 1B Field indicators. N/A = not an indicator for that group. Use information from the tables below to help with resistance group identification. If a resistance group is reached return to instructions for interpretation if not go to Key 2 for more data collection.

ZONE (ECOSYSTEM STATES) DESCRIPTIONS FOR FIELD IDENTIFICATION

Zone (ecosystem state)	Description
Forest	dominated by trees and lacking marsh grasses
Transition	dominated by shrubs or small trees and marsh grasses present
Groundwater seep	dominated by *Phragmites australis* or *Scirpus* spp.
High marsh	dominated by marsh grasses *Spartina patens* or *Distichlis spicata* or rush *Juncus roemerianus*; shrubs, if present, cover < 50 % of area
Low marsh	dominated by marsh grass, *Spartina alterniflora*

FIELD MEASUREMENTS

Measure	Description (unless otherwise stated)
Slope =	elevation difference (m) between seaward forest edge and landward low marsh edge / distance (m) between seaward forest edge and landward low marsh edge
Elevation difference =	elevation difference (m) between seaward end of forest and seaward end of zone adjacent to forest

Key 1B. Continued.

All indicators must be present to choose "YES"

	Indicators	YES	NO
		Resistance to State Change	
L_a	High marsh: N/A Transition: N/A Slope: <0.18 Elevation difference: N/A Forest position: close to tidal creek (w/in 55 m)	**LOW**	Go to Key 2
L_a, L_b or L_c	High marsh: wide (>50 m) Transition: dominated by *Pinus taeda*, *Juniperus virginiana* or *Myrica cerifera* Slope: N/A Elevation difference: N/A	**LOW**	Go to Key 2
L_d	High marsh: N/A Transition: dominated by *Iva frutescens* Slope: <0.01 Elevation difference: ≤0.15 m	**LOW**	Go to Key 2
I_a	High marsh: narrow (<35m) or absent Transition: dominated by *Iva frutescens* or absent Slope: N/A Elevation difference: <0.40 m	**INTERMEDIATE**	Go to Key 2
I_b or I_c	High marsh: narrow (<35 m) or absent Transition: dominated by *Iva frutescens* or absent Slope: >0.01 Elevation difference: <0.4 m	**INTERMEDIATE**	Go to H_b
H_a or H_b	High marsh: very narrow <15 m or absent Transition: very narrow <15 m or absent Slope: N/A Elevation difference: >0.5 m	**HIGH**	Go to L_d
H_a or H_b	High marsh: N/A Transition: absent Slope: N/A Elevation difference: >0.5 m Groundwater seep: present	**HIGH**	Go to Key 2

Key 2. Scoring procedure. Use tables from Key 1A supplement 2 for forest soil types and Key 1B for description of field measurements. When a resistance group is determined go to instructions for interpretation.

Step	Measurement	Category	SCORE
Step 1	Forest Soil Type	Hydric	= 0
		Nonhydric	= 1
Step 2	Elevation difference between seaward edge of forest and seaward edge of adjacent seaward zone	<0.15 m	= 0
		0.15 - 0.30 m	= 1
		>0.30 m	= 2
Step 3	Slope between seaward edge of forest and landward edge of low marsh	<0.01	= 0
		0.01 - 0.02	= 1
		>0.02	= 2
Step 4	Elevation above MSL *	<1.25 m	= 0
		1.25 - 1.40 m	= 1
		<1.40 m	= 2

* If elevation above MSL is unobtainable use the following equation to estimate elevation:

Elevation above MSL = $0.9837(X_1) - 4.1254(X_2) + 0.9667$

X_1 = difference in elevation between the seaward forest edge and the landward low marsh edge

X_2 = slope (same slope as step 3)

Step 5 — Sum scores for steps 1-4

TOTAL SCORE	RESISTANCE
0 - 2	LOW
3 - 5	INTERMEDIATE
6 - 7	HIGH