FRINGE WETLANDS IN ALBEMARLE AND PAMLICO SOUNDS: LANDSCAPE POSITION, FRINGE SWAMP STRUCTURE, AND RESPONSE TO RISING SEA LEVEL

By

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ABSTRACT

The shorelines of Albemarle and Pamlico Sounds are dominated by wetlands. Three large reaches of these shorelines were examined on National Wetlands Inventory maps in order to document the wetland type, zonation of vegetation, and geomorphic characteristics of the shoreline. The southern shoreline of Albemarle Sound is 72 percent wetland and 28 percent upland. Only 1 percent of the shoreline of Alligator River is upland, the remainder being wetland. The shoreline of Croatan Sound and northern Pamlico Sound is 87 percent wetland and 13 percent upland. Vegetation structure in these geographic regions varies with salinity of the estuaries: wetlands in Albemarle Sound and the Alligator River are mostly forested, while wetlands in Croatan Sound and northern Pamlico Sound are marshes. The large coverage of forested wetlands hydrologically affected by sea level in North Carolina is unique in estuaries of eastern United States. Consequently, they are among the least studied and most poorly understood wetland ecosystems.

In freshwater areas where forested fringe wetlands dominate, some sites develop a gradient in species composition, vegetation structure, and hydrology that distinguishes shoreline forest stands from interior wetland sites. At one representative site, red maple and red bay increased in importance and bald cypress decreased in importance with distance from the shoreline. The surface of nearshore sediments is elevated slightly above the wetland interior. Microrelief also becomes greater toward the wetland interior. In brackish water areas zonation of vegetation tends to be determined by salinity, with marsh vegetation near the edge grading into shrubs and trees with increasing distance from the shoreline. These "fringe" wetlands are influenced hydrologically by flushing from wind-influenced water level fluctuations in the sounds, local wave activity, and globally rising sea level. The position of fringe wetlands at the interface between aquatic ecosystems and interior wetlands makes them ecologically important habitats. Their position also requires that they be assessed for the linear extent of the resource, rather than the small surface area that they occupy relative to other wetland types. Forested fringe wetlands provide complex habitat features that are dependent on continuous shoreline erosion.

The hydrology of these wetlands is still poorly understood. Wind direction and force control flooding. Consequently, hydroperiod varies according to the geographic position of the wetland in relation to the estuary. The hydrologic data analyzed from the floodplain of the Chowan River illustrated that the site

was too far upstream to have fringe characteristics. Flooding was due to headwater flooding from the drainage basin rather than shoreline flooding from "setup" of the Chowan River by wind. Consequently, hydrologic characteristics of fringe wetlands in Albemarle Sound remain undetermined.

Because of the distinct geomorphic setting of fringe and interior wetlands with respect to uplands in North Carolina's sounds, commonly used approaches for predicting effects of rising sea level on the coastal plain are inappropriate and misleading. One approach assumes that fringe wetlands gently rise in elevation from the shoreline to uplands, and sea level rise will result in the overland migration of these wetlands. For most of the shoreline of the Pamlico and Albemarle Sounds, this condition is absent because wetlands already occupy much of the area that was upland under conditions of lower sea level stage. In many areas fringe wetlands gently grade into interior swamp forests and pocosins with no meaningful change in elevation and no transition to uplands within distances that would be relevant to the notion of migrating wetlands. Another approach uses contour lines on topographic maps to predict future shoreline positions as sea level rises. This approach ignores the dominant role that wetlands have played in the landscape development in the coastal plain. The interaction of rising sea level and coastal wetlands is complex and varies from one geographic area to another. Alternative approaches to predicting the effects of rising sea level need to be developed for the situation as it exists in North Carolina. An important uncertainty is whether wetlands can sustain themselves when exposed to accelerated rates of rising sea level.

Clearly more information is needed on the sea-level controlled, nontidal fringe wetlands that are so prevalent in the Albemarle and Pamlico Sound regions. The present study is preliminary and has served as an initial characterization from which more indepth research efforts may be developed.

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Background and Problem

Coastal wetlands have received a great deal of attention because of the many biologic, geomorphic, and hydrologic values they provide for society. The extensive coastal wetlands of North Carolina are unique because of the preponderance of wetlands that have fresh water or lack lunar tides in spite of being under the influence of sea level rise. Two wetland types, irregularly flooded brackish marshes and irregularly flooded forested wetlands, are dominant shoreline features in the Albemarle and Pamlico Sound region. They have been little studied and are poorly understood ecologically relative to tidal brackish marshes and tidal freshwater marshes.

Because of the sharp transition that fringe[1] wetlands normally represent between a large body of open water and either upland or additional wetland on the landward side, they are potentially very important areas ecologically, geologically, and hydrologically. Fringe wetlands are considered to be essential fish habitat in brackish portions of estuaries, both in tidal and irregularly flooded wetland types. These wetlands constitute an important component of primary and secondary nursery areas for commercial and sport fisheries. The value of freshwater fringe forests for supporting fisheries is less certain, however, and remains to be explored.

One of the major concerns is whether fringe wetlands can be sustained under projected acceleration in sea-level rise as a result of global warming. To compound this problem is the fact that many of the wetland-upland transition zones are no longer available for migration because they have been occupied by human structures and activities incompatible with overland migration of wetlands. Projected increases in economic development and

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[1]Fringe wetlands are distinguished from <u>riverine</u> and <u>basin</u> (depression) wetlands by hydroperiod, direction of water flow, and zonation of vegetation. Fringe wetlands occur in estuaries where tidal forces dominate or in lakes where water moves in and out of the wetland due to wind, waves, and seiches. In contrast, riverine wetlands tend to be dominated by unidirectional flow, shorter hydroperiod, and higher sediment loads. Basin wetlands (peat bogs, pocosins) receive most of their water from precipitation, have strong seasonal fluctuations in water table, and have weak lateral flow, often limited to sheet flow.

settlement in the coastal zone of North Carolina suggest this issue will become more difficult to resolve in the future. Because of the sparsity of information on fringe wetlands of the type that occur in the Albemarle and Pamlico Sounds, management and protection of these areas have had to rely on management policies developed for wetlands that differ hydrologically and geomorphologically. This places the resource in a potentially vulnerable position if inappropriate management techniques are applied.

Purpose and Approach

The objectives of this project are to: (a) provide a partial description of the distribution and abundance of fringe wetlands along several segments of the shoreline of Albemarle and Pamlico Sounds, (b) describe the species composition and structure of the vegetation for several sites of forested wetland in the Albemarle Sound region, and (c) assemble recommendations on research and management of these wetlands so that action can be taken toward understanding how they function and protecting them for the natural attributes that they provide.

Information on the distribution and abundance of fringe wetlands was derived from National Wetlands Inventory maps. Data on vegetation type, zonation, exposure, and proximity to uplands were summarized from these maps for three geographic areas: southern shore of Albemarle Sound, the Alligator River, and the northern shore of Pamlico Sound. The intention was to provide information that might lead to strategies for management and protection of shoreline wetlands. At a finer scale of resolution, site-specific data on forested fringe wetlands were collected for three sites, one on the Chowan River and two in the Alligator River. (The Chowan River site was chosen principally because hydrologic data were available from a previous study. Upon analysis, it was discovered that the site had hydrologic attributes more similar to a riverine wetland than a fringe wetland. Hydrologic studies on fringe forests in Albemarle Sound remain to be done.) Data on these sites will allow comparison with other forested wetlands and assist in the development of more detailed studies on the dynamics and structure of these ecosystems. Finally, a workshop was held in which managers and researchers developed recommendations for (a) protecting the resource, (b) improving the understanding of how these ecosystems function within an estuarine setting, and (c) anticipating research and management needs under conditions of accelerated rise in sea level.

Results

The shorelines of Albemarle and Pamlico Sounds are dominated by wetlands. The southern shoreline of Albemarle Sound is 72 percent wetland and 28 percent upland. Only 1 percent of the shoreline of Alligator River is upland, the remainder being wetland. The shoreline of Croatan and northern Pamlico Sound is 87 percent wetland and 13 percent upland. Vegetation structure in these geographic regions varies with salinity of the estuaries: wetlands in Albemarle Sound and the Alligator River are mostly forested, while wetlands in northern Pamlico Sound are marshes.

In freshwater areas where forested fringe wetlands dominate, some sites develop a gradient in species composition, vegetation structure, and hydrology that distinguishes shoreline forest stands from interior wetland sites. At one representative site, red maple and red bay increased in importance and bald cypress decreased in importance with distance from the shoreline. The elevation of the nearshore sediment surface is slightly higher than the wetland interior. Microrelief, however, increases toward the forest interior. The outer eroding portion of fringe swamps have a great deal of habitat complexity as revealed by fallen logs, exposed roots, and sheltered areas. Beds of aquatic macrophytes may occur in the shallow waters protected by trees. Erosion, and possibly sea level rise, is likely a necessary condition to maintain this complex habitat structure. Hence, the process of shoreline recession may be thought of as the cost of maintaining this habitat complexity. In brackish water areas, zonation of vegetation structure is controlled by salinity. Marsh vegetation intergrades with shrubs and trees with increasing distance from the estuary. The position and linear configuration of both forested fringe and marsh fringe require that they be assessed for the linear extent of the resource, rather than the surface area that they occupy, which is small, relative to other wetland types.

Hydrology of these forested fringe wetlands has not been resolved and is still poorly understood. Flooding is apparently controlled by wind direction and force as well as seasonal fluctuations in sea level. Consequently, hydroperiod varies according to the geographic position of the wetland in relation to the estuary. From a related study on a nontidal marsh in the southwestern portion of Pamlico Sound, annual cycles of sea level change, wind-driven floods, and evapotranspiration and rainfall control site water balance and hence flooding.

Conclusions of Study

Because of the distinct geomorphic setting of fringe and interior wetlands with respect to uplands in North Carolina's sounds, commonly used approaches for predicting effects of rising sea level on the coastal plain are inappropriate and misleading. In Pamlico and Albemarle sounds, situations where fringe wetlands gently rise in elevation from the shoreline to uplands are uncommon, representing an important departure from normal coastal conditions elsewhere. Hence, sea level rise will not result in the overland migration by these wetlands as is assumed for other areas of the Atlantic coast. Instead, fringe wetlands often gently grade into interior swamp forests and pocosins with no meaningful change in elevation and with no transition to uplands within distances that would be relevant to the notion of migrating wetlands. Projection of future shoreline position through the use of contour lines on topographic maps ignores the dominant historic role that wetlands have played in the landscape development in the coastal plain. Alternative approaches need to be developed for the situation as it exists in North Carolina. An important uncertainty, however, is whether wetlands can sustain themselves when exposed to accelerated rates of rising sea level. Methods need to be developed to predict how accelerating sea level rise will influence fringe wetlands, interior wetlands, and low-elevation uplands in the region of coastal North Carolina.

What has become apparent from this preliminary analysis is the extent to which entire landscapes in the coastal plain, rather than just shorelines, are currently under the influence of rising sea level. The wetlands that are responding to rising sea level are among the least understood ecologically. The lack of appropriate models for predicting the effects of sea level rise, especially models that can accommodate the dominant landscape role that wetlands have played historically, has hindered progress in developing strategies for the management and protection of natural attributes of estuarine shorelines in North Carolina. Concepts developed for coastal wetlands elsewhere may be misleading when applied to North Carolina's estuaries. If wetlands are to be protected for their natural ecological attributes, then much of the shoreline surveyed is inappropriate for alternative uses (e.g., agricultural, residential, commercial, and urban development) because wetlands dominate the shoreline.

Recommendations

Panels consisting of managers and researchers met on March 1, 1989 to offer their recommendations on the response of fringe wetlands in the state to sea level rise. Emphasis was placed on the sea level controlled, but largely nontidal wetlands of the Albemarle and Pamlico Sounds. A summary of the recommendations appears in Appendix E of this report.

INTRODUCTION

Coastal wetlands under the influence of sea-level rise have received a great deal of attention because of the many biologic, geomorphic, and hydrologic values they provide for society (Chapman 1976, Odum et al. 1974). Both salt water and daily tidal cycles are normal characteristics of coastal wetlands. The extensive coastal wetlands of North Carolina are unique because of the preponderance of wetlands that have fresh water and lack tidal influence. Two wetland types, irregularly flooded brackish marshes and irregularly flooded forested wetlands, are dominant in the Albemarle and Pamlico Sound region (Wilson 1962). They have been little studied and are poorly understood ecologically relative to tidal brackish marshes (Pomeroy and Wiegert 1981, Teal 1986) and tidal freshwater marshes (Simpson et al. 1983, Odum et al. 1984).

The hydrologic and geographic setting of Albemarle and Pamlico Sounds (Figure 1) departs sharply from the remainder of the Atlantic coast. The presence of the barrier islands restricts the exchange of water with the ocean, resulting in lower salinities and lower amplitude tides than elsewhere (Copeland et al. 1983 and 1984, Giese et al. 1985). Tides and salinity are the two most important controls on vegetation in these sea-level controlled, coastal wetlands (Figure 2). The presence or absence of the semidiurnal astronomic tides separates wetlands into tidal and nontidal. Where salt water is present, swamp forest is absent because no woody species at this latitude are tolerant to high salinity. Halophytic species such as black needlerush (<u>Juncus</u> <u>roemerianus</u> Scheele) dominate under saline conditions along with an assemblage that may include salt grass (<u>Distichlis spicata</u> Greene), saltmeadow cordgrass (<u>Spartina</u> <u>patens</u> (Aiton) Muhl.), and big cordgrass (<u>S.</u> <u>cynosuroides</u> (L.) Roth) (Cooper and Waits 1973). This ecosystem type has widespread occurrence in the Pamlico Sound region. In such situations, water level fluctuations caused by wind direction and force become dominant. In Albemarle Sound, the normally fresh or oligohaline conditions favor the development of forested wetlands rather than marshes. Well over 100 kilometers of shoreline are occupied by forested wetlands in this region. Little information has been developed for this wetland type because it is so scarce in areas outside of North Carolina. In Currituck Sound, salinity of water decreases from its juncture with Albemarle Sound to fresh water in the northern part of the sound. Infrequent episodes of overwash of sea water create brackish conditions (Currituck Sound Task Committee 1980).

Figure 1. Map of Albemarle-Pamlico estuarine study area (adapted from a map produced by N.C. Land Resources Information Service, April 1989). Work reported in this report is restricted to Albemarle Sound and northern Pamlico Sound.

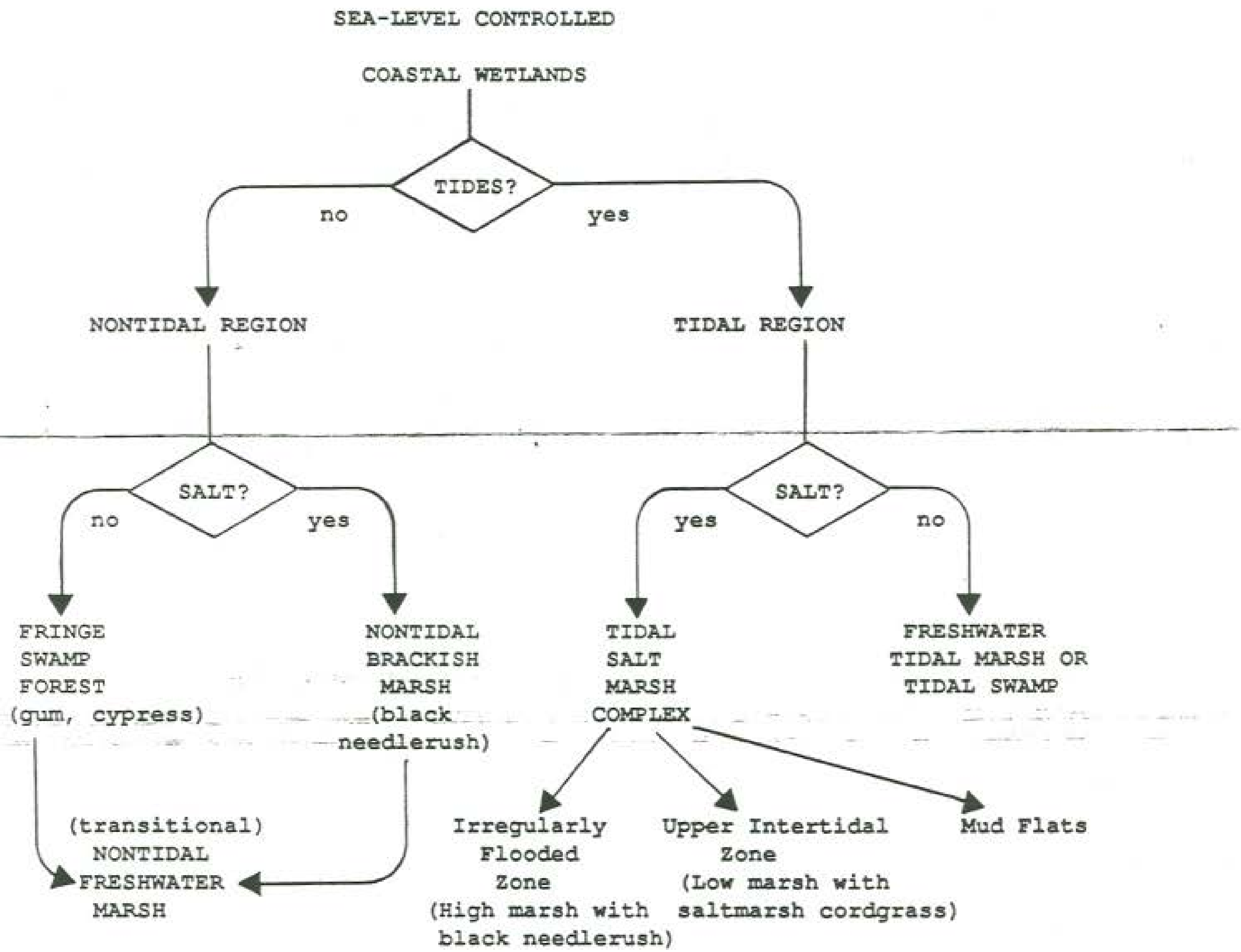

Figure 2. Factors controlling the expression of plant community physiognomy and species composition of coastal wetlands in North Carolina. Both tidal and nontidal regimes support marshes because the vegetation is controlled principally by salinity rather than hydrology. Forested wetlands occur where salt is lacking. Nontidal freshwater marsh is a transitional type between fringe swamp forest and nontidal brackish marsh.

Within the tidal category (Figure 2), tidal freshwater marshes and swamps may develop, but these communities are virtually absent from the Albemarle-Pamlico region because of the lack of tides in the low salinity portions of our estuaries. Tidal freshwater marshes occur in Virginia (Odum et al. 1984, Odum 1988) and further south in North Carolina (Rozas and Hackney 1984). Where salt water and semidiurnal tides co-occur (Figure 2), as in areas in close proximity to the inlets, saltmarsh cordgrass (Spartina alterniflora Loisel.) communities develop in the upper intertidal zone (Adams 1962, McKee and Patrick 1989). Associated with these tidal marshes is a landward zone that receives most of its flooding from spring tides, wind-generated floods during storms, and precipitation. These irregularly flooded brackish marshes, or "high marshes", are usually present wherever tidal salt marshes are found. Their vegetation resembles that of the nontidal marshes described above. The principal difference is landscape position. In Pamlico Sound, nontidal brackish marshes border the open waters of the estuary with no intervening zone of S. alterniflora as found in tidal marshes (Brinson, in press).

A classification as simple as Figure 2 is not without exceptions. Most of these exceptions occur in transitional areas between tidal and nontidal, and between brackish and fresh water. The extent to which diminution of the tidal influence affects species composition has not been well resolved for this region. Parallel changes in salinity make difficult the separation of salinity and tides as controls of species composition. Plant community type has an imperfect correspondence with salinity. In Currituck Sound, for example, the low salinity of the water would suggest that more forested wetlands should be present. Marshes of saw grass (Cladium jamaicense Crantz) and J. roemerianus in that region and other "freshwater" localities in Albemarle Sound may be explained by episodes of salinity intrusion. In Currituck Sound barrier island overwash during severe storms cause elevated salinities (Currituck Sound Task Committee 1980). Consequently, marshes may be simply remnants of former, more brackish conditions. Also, disturbance by fire would tend to sustain marshes rather than forests.

Because of the sharp transition that fringe wetlands* normally represent between a large body of open water and either upland or additional wetland on the landward side, they are potentially very important areas ecologically, geologically, and hydrologically. Fringe wetlands are considered to be essential fish habitat in brackish portions of estuaries, both in tidal (Kneib 1984, Rozas and Odum 1987, Hettler 1989) and nontidal wetland types (Marraro et al. in press). Shallow regions at the interface between wetlands and open water may be especially important habitat. McIvor and Odum (1988) demonstrated that the shallow margins of freshwater tidal marshes provide greater abundance of invertebrate prey and more protection from predators than steeper sloped erosional banks. From the terrestrial side of the transition, access to open water areas by many terrestrial animal species is provided by fringe wetlands. Fringe wetlands are also buffer zones between uplands and waters of the estuaries which may have important local effects on nonpoint sources of pollution (Phillips 1989a, b).

Fringe wetlands experience hydrologic flushing during water level fluctuations, whether the source is lunar or wind-generated. Tidal salt marshes and mangroves are some of the most hydrodynamically active ecosystems that support the growth of higher plants. Where astronomic tides are lacking and flooding is irregular, flushing diminishes in proportion to the frequency and amplitude of water level fluctuations. Hence, ecosystem characteristics that typify fringe wetlands would tend to be ameliorated in low energy fringe wetlands.

Unless sediment supplies are large, as they are in the fringe wetlands of deltaic environments, shoreline erosion due to local wave activity may have profound effects on the structure of these ecosystems. In Pamlico and Albemarle Sounds, most of the sediments derived from continental sources is deposited subtidally (Pickett and Ingram 1969) leaving little available for marsh building processes. Supplies are insufficient and distribution is inadequate to compensate for shoreline losses due to wave-induced erosion. Because of the large size of the estuaries, fetch is usually adequate for strong wave activity to develop. Mean shoreline recession rates in North Carolina's sounds range from negligible to as high as 6 m per year (Stirewalt and Ingram 1974, USDA Soil Conservation Service 1975, Bellis et al. 1975).

Rising sea level has been important in the development of fringe wetlands. Most estimates of rates of rising sea level for east coast of the United States fall in the range of 1 to 5 mm/yr (Stevenson et al. 1986). The effects of sea-level rise, however, are often confused with shoreline erosion. Although most would

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* Fringe wetlands are distinguished from <u>riverine</u> and <u>basin</u> (depression) wetlands by hydroperiod, direction of water flow, and zonation of vegetation (Brinson 1988, Lugo et al. 1988). The term refers to the geomorphic position and hydrology of the wetland rather than its vegetation. Fringe wetlands occur in estuaries where tidal forces dominate or in lakes where water moves in and out of the wetland due to wind, waves, and seiches. In contrast, riverine wetlands tend to be dominated by unidirectional flow, shorter hydroperiod, and higher sediment loads. Basin wetlands (peat bogs, pocosins) receive most of their water from precipitation, have strong seasonal fluctuations in water table, and have weak lateral flow, often limited to minor sheet flow.

agree that long-term sea-level rise has been responsible for marine transgression as illustrated by changing positions of barrier islands and coastlines (Kraft et al. 1987), both shorter term sea-level fluctuations and storm activity alone can explain most of the shoreline erosion that takes place (Komar and Enfield 1987). Shoreline erosion occurs when local sediment export exceeds import, processes which are relatively independent of sea-level rise but closely tied to fetch and exposure. In contrast, sea-level rise under certain conditions compensates for wetland losses due to shoreline erosion by causing wetlands to migrate landward. Consequently, it is possible for shoreline erosion to result in no net loss of wetland area if an equivalent amount of wetland encroachment occurs in uplands. This paradigm of wetland migration has been developed for many of our coastal marshes (Titus 1988b). Several circumstances could lead to net loss of fringe wetlands, however. First, a steeper slope landward from the wetland would lead to a narrower zone occupied by the wetland once migration occurred. Second, there is uncertainty of whether wetlands will be able to maintain a favorable position with respect to sea level with the accelerated rates projected during global warming. To compound this problem is the fact that many of the wetland-upland transition zones are no longer available for migration because they have been occupied by human structures and activities incompatible with overland migration of wetlands. Projected increases in economic development and settlement in the coastal zone of North Carolina suggest this issue will become more difficult to resolve in the future as options become more limited (Day and Templet 1989). Finally, the mechanisms of wetland loss do not occur only by shoreline erosion, but more often are the result of deterioration from the interior. Within-marsh deterioration has been documented as a major mode of wetland loss in the Mississippi delta region (Browder et al. 1985) and for marshes in Chesapeake Bay (Stevenson et al. 1985, 1986).

Because of the sparsity of information on fringe wetlands of the type that occur in the Albemarle and Pamlico Sounds, management and protection of these areas have had to rely on management policies developed for wetlands that differ hydrologically and geomorphologically. This places the resource in a potentially vulnerable position if inappropriate management techniques are applied. This report is a preliminary description of fringe wetland types that occur in this geographic area. The report will: (a) provide a partial description of the distribution and abundance of fringe wetlands in sections of the Albemarle and Pamlico Sounds and (b) describe the species composition and structure of the vegetation for several sites of forested wetland in the Albemarle Sound region. The geographic information was derived from National Wetlands Inventory maps. They were analyzed to develop a geographic description of fringe wetland, such as the proportion of shoreline occupied by uplands and by wetlands of various types. The intention was to provide information that might lead to strategies for management and protection of shoreline wetlands. At a finer scale of resolution, site-specific data on forested fringe wetlands were collected for three sites, one on the Chowan River and two in the Alligator River. The Chowan River site was chosen principally because hydrologic data were available from a previous study. (As it turned out, the site had hydrologic attributes more similar to a riverine wetland than a fringe wetland.) Data on these sites will allow comparison with other forested wetlands and assist in the development of more detailed studies on the dynamics and structure of these ecosystems.

STUDY AREA

Previous Studies

Very little information was available on the fringe swamps that border Albemarle Sound. The three most relevant sources are a master's thesis by Blanck (1980), a Sea Grant publication by Bellis et al. (1975) with associated maps (Riggs et al. 1978), and a forested wetland study in the South Creek area of the Pamlico River by Brinson et al. (1985). The thesis deals mostly with the photosynthetic response of bald cypress (Taxodium distichum (L.) Richard) and water tupelo (Nyssa aquatica L.) to light intensity and conditions most favorable for seed germination for the two species. Both sets of experiments were conducted under controlled environmental conditions. In addition, ages of cypress trees were determined at a field site which was described as a "cypress fringe", a nearshore strand of cypress trees in Albemarle Sound. It was suggested that these trees act as natural bulkheads to deter erosion of the shoreline just to the landward side of the fringe where water tupelo is dominant. Observations were confined to this outer strand and no quantitative information was included on forest structure and species composition landward of the cypress fringe.

Bellis et al. (1975) conducted an extensive shoreline survey that included both Albemarle and Pamlico Sounds. Its purpose was to classify shorelines by their morphology and vegetation as a basis for predicting shoreline recession by erosion. Major classes of shoreline were swamp forest, grass marsh, and sand and clay banks. Separate maps were developed for the Albemarle Sound, Pamlico River and northern Pamlico Sound, Neuse River estuary, and the Core-Bogue Sound systems (Riggs et al. 1978). The distribution of shoreline categories, as percent of total shoreline, was very similar for the Pamlico, Neuse, and Core-Bogue areas (Table 1). The Albemarle region differed by having nearly one-fourth (163 km) of its shoreline in swamp forest, a category that was either lacking completely or trivial for the other regions. Backbarrier marshes were not included in the survey.

The sand and clay bank shoreline class was further subdivided into low (1-5 feet tall), high (5-20 feet) and bluff (>20 feet). Shoreline recession was judged negligible in the swamp forest class regardless of exposure to wave action and varied between 1 and 20 feet per year for other classes depending on bank height and shoreline exposure. Erosion rates were acquired from a study by the USDA Soil Conservation Service (1975) which were estimated by comparison of aerial photographs over intervals ranging from 22 to 32 years.

The study by Brinson et al. (1985) examined litterfall and vegetation structure of four sites that encompassed a range of hydroperiods and salinities. The study sites were located at the head of estuarine creeks where vegetation changed from brackish marsh to forested wetland. Rising sea level and intrusions of brackish water during drought years were suggested as forces that caused brackish marsh to migrate upstream and invade the forested wetland. Rather than migration occurring gradually year-by-year, it was suggested that trees are killed and marsh invades during drought years when salinities are high because of lack of freshwater runoff. This process of upstream migration is an early phase of estuarine development and landscape evolution, and is consistent with the drowned river valley origin of North Carolina's estuaries.

Table 1. Distribution of five shoreline categories by geographic region. From Riggs et al. (1978).

Shoreline category	Geographic region[1] Albemarle	Pamlico	Neuse	Core-Bogue	Totals
		Distance in kilometers			
Low bank	256	180	200	122	758
High bank	95	31	39	14	179
Bluff	6	8	19	0	34
Swamp forest	163	11	3	0	177
Marsh	182	547	467	220	1416
Total km	702	777	727	357	2563
		Percent of total shoreline			
Low bank	36	23	27	34	30
High bank	14	4	5	4	7
Bluff	1	1	3	0	1
Swamp forest	23	1	0	0	7
Marsh	26	70	64	62	55

[1] Of the total shoreline length in Albemarle Sound, Dare Co. contributed 23.9% and eight counties (Bertie, Camden, Chowan, Currituck, Pasquotank, Perquimans, Tyrrell, Washington) contributed <15% each. Pamlico distribution was 51.7% in Hyde, 40.0% in Beaufort, and 8.3% in Pamlico Counties. Neuse distribution was 49.1% in Pamlico, 25.9% in Carteret, and 25.0% in Craven Counties. Core-Bogue was all in Carteret County.

Specific information is available for the Chowan River region as a result of several studies initiated in the 1970s in response to blue-green algal blooms on the lower river. The hydrologic data in this report were collected during the study by

Daniel (1977). Data on biomass production and nutrient turnover of aquatic macrophytes communities in the littoral of the lower Chowan River are reported in Twilley et al. (1985). Spatter-dock (Nuphar luteum (L.) Sibthorp & Smith) and Justicia americana (L.) Vahl. are dominant species. These stands are interspersed among cypress snags along protected regions of shoreline. Plants and associated invertebrate communities may represent an important source of food and cover for fish and food for terrestrial animals occupying the most exposed portion of the fringe wetland.

A study of the sedimentology of the lower Chowan River floodplain (Witner 1984) reported that accumulation of clastic and organic sediments began 4,600 y B.P. in channels cut by tributaries of the river on the pre-swamp surface. Sediments were classified according to their organic matter (OM) content as peat (>75% OM), very peaty (50-75% OM), peaty (25-50% OM), and clastics (<25% OM). Only one profile 7 m in depth contained a continuous accumulation of very peaty sediment. Deposits of peat and very peaty sediments occurred in as many as five individual layers separated by clastics and peat. This layering increased toward the upper reaches of the lower Chowan, apparently in response to greater fluvial influence.

Information on nontidal brackish marshes is much more abundant. Marshes dominated by Juncus roemerianus, Spartina cynosuroides, and other freshwater to brackish tolerant species were described in the South Creek area and aboveground biomass accumulation for several community types was estimated (Bellis and Gaither 1985). Marshes that occur in the protected margins of these tributaries vary in species composition over short distances. The marshes appear to be migrating upstream into forested wetlands of the tidally influenced floodplains of the tributaries (Brinson et al. 1985).

Information is becoming available on broader expanses of marsh that occur on former interfluves and islands in Pamlico Sound (Brinson in press; A. Anderson, personal communication, 1988; W. Kirby-Smith, personal communication, 1988). These large marshes are dominated by J. roemerianus with Spartina patens, S. cynosuroides, Distichlis spicata, and Cladium jamaicense either being locally dominant or mixed with J. roemerianus (Knowles 1989). Where the shoreline of these marshes is exposed to high wave energy, wetland is lost to erosion at the same time that a storm levee develops along the retreating margin (Brinson et al., in press a). Because the elevation of this levee is higher than interior portions of the marsh, drainage of rainfall and estuarine flood waters from the marshes is impeded. Salinity of the interstitial water of the surficial sediments decreases from marsh edge to interior (Brinson et al., in press b) where low salinities allow salt intolerant species to persist, most notably trees and shrubs. This transition from dominance by marsh grasses, through a mixture of marsh and shrubs, and finally to a forested plant community is common in the fringe wetlands of Pamlico Sound. The effects of hydroperiod and salinity are hard to separate because they both tend to decrease parallel to one another from marsh edge to interior (Hook 1988).

If Cedar Island marsh is representative of the brackish marshes of Pamlico Sound, fish are more widely distributed than previously thought. Fish have been collected and observed over 2 km from the shoreline in the Cedar Island marsh (Marraro et al. in press). The long distance, lack of current for orientation, and the high density of the vegetation argue that these fish are members of marsh resident populations rather than a migratory assemblage that moves between the estuary and the marsh interior. The presence of these fish is likely to have a strong influence on aquatic food webs of the marsh. Gambusia affinis, Cyprinodon variegatus, and three species of Fundulus were the dominant species found on Cedar Island marsh. Diets range from aquatic insects to detritus. Several species of rails nest on the marsh and overwinter there (Davis et al. in press).

Reconnaissance

Because so little was known about forested wetlands of the region in comparison with the brackish marshes, we established three study sites to provide descriptive information on species composition of the forests, qualitative information on sediments, and elevation of the forest floor (at two sites only). In the process of choosing these sites, we visited a number of fringe swamps during fall 1987 along the northern side of the Albemarle Sound including the Chowan, North, Pasquotank, and Little Rivers, and Big Flatty Creek as well as several sites along the Alligator River. Observations were made on species composition of the forest at the edge and along transects ranging from several tens of meters to approximately 1 km. A number of samples were taken with a Macauley peat sampler to determine the depth and texture of sediments. One of the primary purposes of these surveys was to gain a qualitative impression of the vegetation and geomorphology of fringe swamps in the region. This aided in choosing representative sites for more intensive study. The rationale for choosing these sites is given below. Ideally, random sampling or sampling stratified among physiographic features should be used, but time and resources did not permit a such an approach for choosing study sites.

Choice of Representative Forested Wetland Sites

The original objective was to choose three representative sites for vegetation analysis along transects that sloped gently upward from the shoreline, through the wetland, and ending at the wetland-upland transition. It soon became apparent during the field visits that this type of geomorphology was rare and unrepresentative of fringe wetlands in the region, and the criteria were abandoned. As described later, there are many sites where wetlands continue more than 2 km inland with no apparent rise in elevation and no upland. Even where the zone of wetland is narrower, as along some of the tributaries on the north side of Albemarle Sound, the soft sediments of the wetland do not change in texture or become shallow enough to have an influence on vegetation until the wetland abruptly ends at the transition to upland.

A common and representative example of transition of vegetation was a sequence of: (1) dead or dying cypress trees under permanently flooded conditions near the shoreline, (2) fairly well stocked forest on a slightly elevated levee near the shoreline, and (3) a subtle change in species composition as well as diminished height of trees toward the swamp interior. There were many variations on this basic theme, however, some likely due to timber harvests and others unexplained. Other criteria for site selection, besides being representative, were access by land and water and permission to work on the sites.

One of the reasons for choosing Rayes Beach on the Chowan River was the availability of hydrologic information from the mid 1970s. As it turned out, the site was under more riverine influence than representative of most fringe swamps, but the hydrologic information made this site attractive for acquiring more information. The Grapevine Landing and Poplar Ridge Point (henceforth called Poplar Point) sites were clearly remote from significant alluvial sources and both met other criteria. The close proximity of the sites normally would have eliminated one of them from consideration had the sediment textures not differed so greatly. Grapevine Landing has predominately clayey inorganic sediments that quickly grade into a dense clay, while the Poplar Point sediments are a thick layer of highly organic sediments.

Map Survey

Initially, aerial photographs from the Agriculture Stabilization and Conservation Service, and 7.5 minute quadrangle maps from U.S. Geological Survey were to be examined for shoreline characteristics and the nature of the forested wetlands in the Albemarle Sound region. However, National Wetlands Inventory (NWI) maps had recently become available for the southern shoreline of Albemarle Sound including the Alligator River, as well as shorelines of the Croatan and Pamlico Sounds. Because the remote sensing technology and expertise used to develop these maps was much greater than that available for our initial approach, the NWI maps were used in conjunction with the 7.5 minute quadrangles to supply information on shoreline characteristics and vegetation cover of fringe swamps. NWI maps for the northern Albemarle

Sound were being developed while our work was in progress and are projected to be available in draft form in mid 1989.

METHODS

Analysis of National Wetlands Inventory Maps

Data on the shoreline and fringe wetlands were made along a continuous section of the estuarine coast from near the mouth of the Roanoke River in Albemarle Sound (Westover quadrangle), east to Roanoke Sound including part of Roanoke Island, in the Alligator River, and south and southwest approaching the village of Swanquarter (Bluff Point quadrangle) (Figure 3). National Wetlands Inventory maps and U.S. Geological Survey topographic maps were the source of most of the information on shorelines (Appendix A). Points for sampling were established by systematically marking the shoreline at 0.5 km intervals by using a divider (Figure 4). No points were established in streams or within embayments which had openings less than 0.5 km wide. Consequently, the sum of the 0.5 km segments would grossly underestimates shoreline length. Shoreline lengths in this report should be regarded relative only to one another.

Information collected at each point included fetch, distance to the 6 foot depth contour, width of the "foul" zone, shortest distance to upland whether along the shoreline or toward the interior without an intervening body of water, compass orientation toward which shoreline is exposed, and the National Wetlands Inventory vegetation cover classifications. From each point a line was projected perpendicular to the shoreline to measure distance across water to the next shoreline or to 20 km, whichever was smaller. Additional distances of unobstructed water surface were measured at 45 degree angles on either side of the perpendicular, and the three values were averaged as an index of fetch, or exposure of uninterrupted distance of water surface. Similarly, distances to the 6 foot water depth contour and distance to the "foul area" boundary were measured to the nearest 10 m along the perpendicular line. Where no 6 foot contour was encountered, such as in shallow embayments, values were omitted from summary statistics. Foul area refers to shallow water along the shoreline that contains stumps, logs, and other debris that hinder navigation. Distance to upland was measured from each point on the shoreline, up to a maximum of 2000 m. The shortest distance to upland, rather than the distance perpendicular to the shoreline was used. The rationale for these upper limits was that shoreline and wetland processes would be insensitive to distances above these values. A consequence was that averages for geographic regions derived from these data sets are reduced and differences among regional averages would be diminished. The exposure of the shoreline, as determined from the compass direction of a line perpendicular to the shore, was determined to

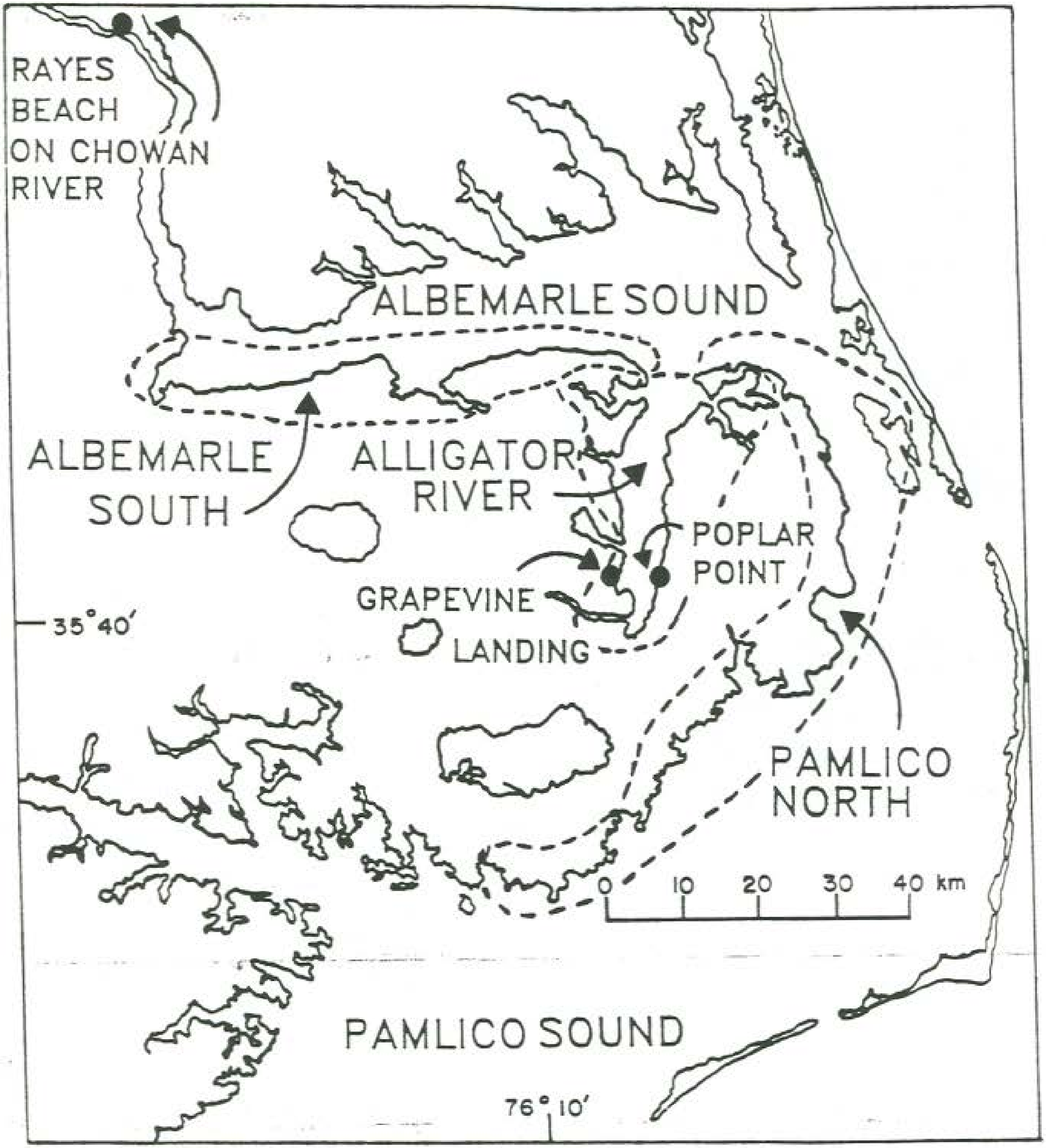


Figure 3. Map of study area showing geographic areas (within dashed envelopes) used for summarizing shoreline characteristics from NWI maps. Filled circles show location of three sites for more detailed descriptions.

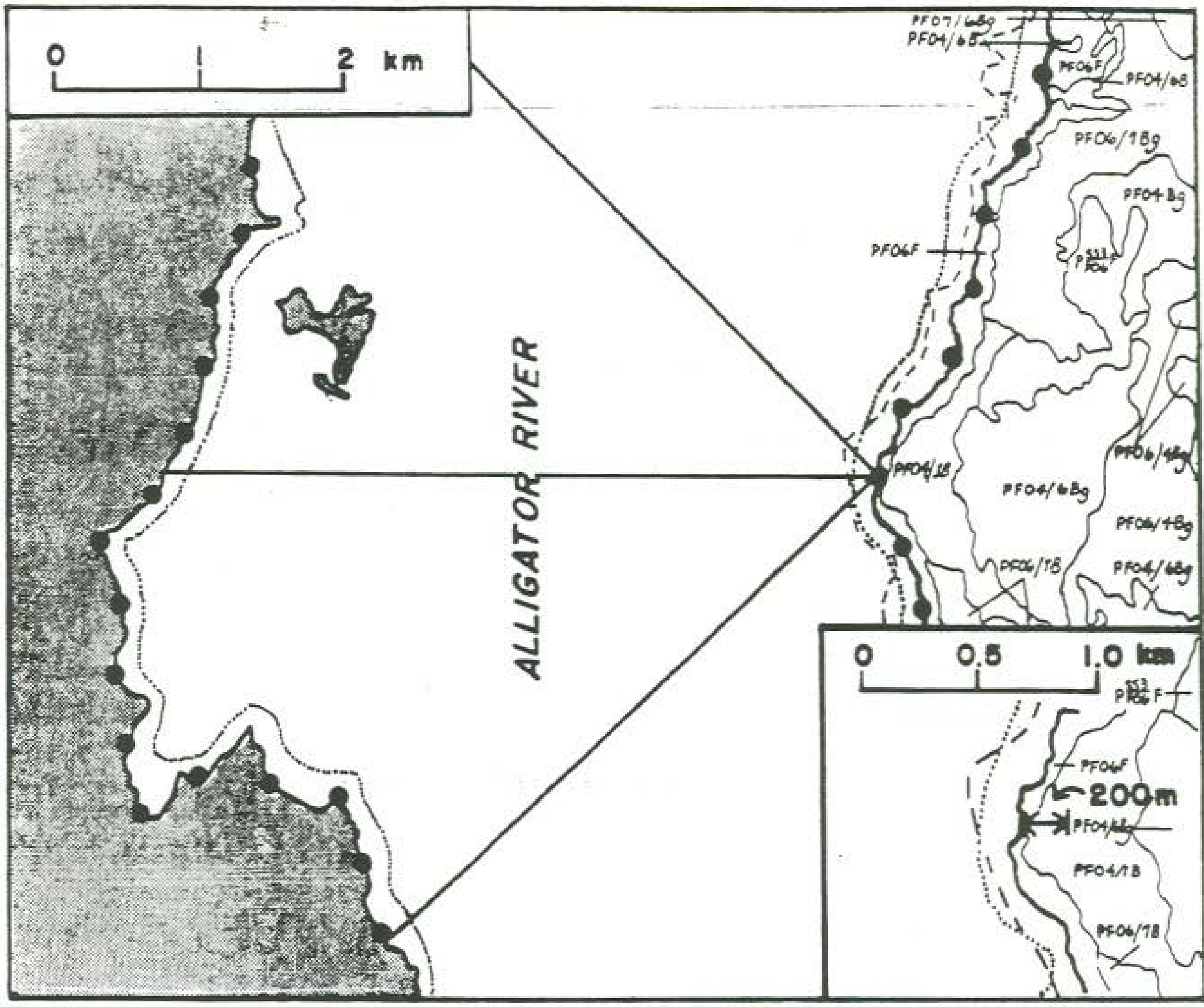


Figure 4. Part of a NWI map illustrating sampling points and other features of the shoreline. Sampling points are represented by dots nominally spaced at 0.5 km intervals along shoreline. Fetch was calculated as the mean of three distances from a point on the shoreline to the opposite shore as illustrated by the length of the three lines drawn across the Alligator River (one perpendicular to shoreline and the other two at 45 degree angles from perpendicular). Zonation of NWI cover types was designated as those NWI types within 200 m of the shoreline as shown in the inset. The example shows that the first wetland type encountered was PFO6F and the second was PFO4/6Bg. No more than three cover types were encountered at each point. NWI wetland types were aggregated into the community types listed in Appendix B. Distance to the 6 foot contour (- - - - -) and foul boundary (.........) were measured from each point perpendicular to the shoreline.

the nearest 5 degrees compass direction. These data are summarized in a ratio of north-facing to south-facing points (e.g., all points less than 90° and greater than 270° were designated as north-facing. A ratio of N:S of 1.0 indicates equal numbers of points exposed predominantly northwards as southward in a geographic region.

NWI cover types and upland within a 200 m zone of the shoreline were recorded in sequence from shoreline to interior. The 200 m zone was anticipated to be the region most strongly influenced by estuarine hydrology based on field reconnaissance. No more than three wetlands were encountered within this zone. All data were transcribed to a data book and the values were independently verified at a later date by a second observer. After verification and correction, if necessary, data were entered into Lotus 1-2-3 files for analysis. The printouts were proofread for transcription errors. NWI wetland types were simplified by aggregating them into fewer and more easily recognizable community categories: brackish marsh, marsh-shrub transition, bottomland hardwoods, maple-gum-cypress, cypress-water tupelo, pocosin and bay forest, miscellaneous, and upland. The vegetation types used and their corresponding NWI types are listed in Appendix B. This is a modification of a recommendation of the Fish and Wildlife Service for aggregating NWI types in South Carolina (John Hefner, FWS Atlanta, personal communication, 1988).

<u>Vegetation Analysis and Site Descriptions</u>

At each of the three sites (Figure 3), transects were established perpendicular to the shoreline and extended from the shoreline toward the wetland interior. Quadrats of 20 m x 20 m size were staked at three locations along the transect: at the shoreline (0-20 m), at an intermediate distance (100-120 m at Chowan; 120-140 m at Grapevine Landing; 140-160 m at Poplar Point), and at the interior site (200-220 m at Chowan; 220-240 m at Grapevine Landing; 280-300 m at Poplar Point). The shoreline location at each site began at what could best be judged as the transition between intermittent and permanent flooding. The interior site was chosen to be representative of the forest type of the larger area landward of the fringe zone. The intermediate site was established between the shoreline and interior sites to describe vegetation in the transition. Coordinates were 36°22'40"N, 76°50'25"W for the Chowan River site at Rayes Beach, 35°30'45"N, 76°02'42"N at Grapevine Landing, and 35°44'48"N, 76°00'11"W for Poplar Point.

Within each of the quadrats, woody vegetation ≥2.5 cm diameter at breast height (1.5 m) was measured and identified. Taxonomic names follow those of Radford et al. (1968) and are listed with vernacular names in Appendix C. Diameters of dead trees were measured and they were counted, but species were not identified. At the Chowan River site, the shoreline quadrat was subdivided into four 10 m x 10 m quadrats to aid in revealing the amount of variation in community structure within a quadrat. At each of the sites, some vegetation extended toward the water beyond the shoreline quadrat either because of irregularities in the shoreline boundary or because trees were isolated from the shoreline community by erosion of surrounding sediments. In these cases measurements were made as described above. However, areal coverage for calculating density was estimated by the irregular area occupied by the trees. Absolute density and dominance data of the smaller plots would not warrant comparison with the larger plots because of the increased edge effect created by the smaller size of quadrats and the arbitrary manner in which boundaries were established.

Profiles of sediment were examined at 1 foot (0.3 m) depth intervals along each of the three transects with a Macauley peat sampler. Samples were taken and described at 20 m intervals along the Chowan River and Poplar Point transects, but less frequently along the Grapevine Landing transect because of shallowness of sediment deposits did not lend themselves to detailed profile descriptions. Levels of the forest floor surface at Grapevine Landing and Poplar Point were taken at 20 m intervals or more frequently. An optical automatic level (Topcon Model AT-F2 with 40-power scope) was checked for collimation adjustment before use. A telescoping staff, graduated in 5 mm increments, was read to the nearest 1 mm. Intervals of leveling were not predetermined, and depended on how homogeneous the forest floor appeared. Generally more frequent levels were determined for uneven topography. Because no absolute elevations were accessible for the sites, data are reported relative to the water level in the Alligator River at the time of measurement. The rise and fall method was used to calculate levels and corrections for closing error were made by allocating error among turning points on backruns and foreruns (Whyte 1976).

Treatment of Hydrologic Data

During 1974 - 1976, the U.S. Geological Survey conducted a hydrologic study of the Chowan River (Daniel 1977). The study assessed groundwater discharge from the fringing swamp as a possible source of water to the river. Three water level recorders were installed in the swamp at Rayes Beach as part of the larger hydrologic study. The recorders were placed on the floodplain 45 m, 235 m, and 810 m from the river's shoreline and nominal elevations of the forest floor were determined by second order leveling from second order bench marks. The records begin in July 1974 and terminate in January 1976 with intermittent periods of instrument malfunction. Records of precipitation and stage of the Chowan River channel were also available and were used to determine the source of flooding in the fringe swamp.

Daily precipitation records were averaged for Lewiston, Edenton, Elizabeth City, and Murfreesboro to approximate the amount received in the region. River stage data were taken from recorders at Harrellsville 12.8 km downstream from Rayes Beach and at Winton, 8.8 km upstream from Rayes Beach. These data were made available by Charles Daniel, III of U.S.G.S. on magnetic and printed media for analysis. Flood events were extracted from the data set and graphed. Precipitation and river stage records prior to and during these events were examined, and were used to reconstruct the nature of the flooding event.

RESULTS

Shoreline Evaluation

Data were aggregated into three geographical areas shown in Figure 3: Albemarle South, Alligator River, and Pamlico North. The rationale for choosing these groups was to establish landscape units on the order of tens of kilometers that would be somewhat homogeneous in wetland vegetation type and possibly other shoreline characteristics. Exact boundaries of the a priori choice of geographic areas were refined to correspond to relatively sharp transitions between marsh and forested wetlands along the shoreline. The three regions represented different salinity regimes and had different amounts of exposure to wave activity. For example, shorelines along Albemarle South are in a low salinity part of the estuary, but the reach has direct exposure to long fetch. Alligator River also has low salinity, but relatively short fetch. Pamlico North is generally exposed to long fetch and occurs in a higher salinity regime than the other regions.

Wetlands occurred at a greater number of points than uplands along the shoreline of each of the three areas (Table 2). Albemarle South had the greatest percentage of upland (28%) while the shoreline of Alligator River was almost entirely wetland (99%). Interspersion between upland and wetland within 200 m of the shore was most frequent at Albemarle South where 10% of the points had uplands at the shoreline and wetlands toward the interior. The opposite arrangement was found at 13% of the sites. Interspersion was lower by comparison in Pamlico North and nearly lacking in the Alligator River because of the infrequency of uplands.

The number of NWI wetland types encountered within the 200 m fringe zone was used to determine zonation and expressed as percent of total encounters (Table 2). Points with either one or two wetland types within this zone were similar in number and dominated over points with three wetland types. Between 38% and 51% of the points had one or two wetland types, while only between 6% and 14% had three. Pamlico North ranked lowest in this regard which may be due to the prevalence of marshes which have fewer species assemblages recognized by NWI categories than wetland forest cover types. Average number of categories per point, including uplands, was 1.7 for Albemarle South and Alligator River, and 1.6 for Pamlico North.

Geomorphic features that were measured included exposure, fetch, distance to the 6 foot water depth contour, and distance

Table 2. Summary of shoreline characteristics for portions of Albemarle and Pamlico Sounds.

Characteristic	Albemarle South	Alligator River	Pamlico North
LENGTH AND DISTRIBUTION			
Nominal shoreline length (km)	94	169	209
Percent of shoreline as:			
Upland	28	1	13
Wetland	72	99	87
INTERSPERSION OF UPLAND AND WETLAND IN 200 M ZONE			
Percentage of points as:			
Upland only (no interspersion)	17	0	5
Wetland only (no interspersion)	60	98	85
Upland to wetland transition	10	1	8
Wetland to upland transition	13	1	2
Percent wetland with transition to upland	18	1	2
Percent upland with transition to wetland	37	100	60
ZONATION OF WETLAND TYPES			
Percentage of points with:			
Only one wetland type	43	38	51
Only two wetland types	47	48	43
Three wetland types	10	14	6
Total number of NWI encounters within 200 m zone	314	596	646
Average encounters per point sampled	1.67	1.76	1.55
GEOMORPHOLOGY			
Exposure (N:S ratio)	5.9	1.1	0.87
Average fetch (km)	9.9	4.4	10.2
Width of "foul" zone, m (% of points)[1]	101(100)	85(100)	26(13)
Width of 6 foot contour, m (%)[1]	677(100)	482(93)	861(87)
Distance to upland (m)	658	1776	1211

(Continued)

Table 2. Concluded.

Characteristic	Albemarle South	Alligator River	Pamlico North
SHORELINE CATEGORIES AT SHORELINE (Percent of total points sampled)			
Brackish Marsh	1.0%	6.5%	65.3%
Marsh-Shrub Transition	--	4.9%	14.4%
Bottomland Hardwoods	2.2%	2.2%	0.8%
Maple-Gum-Cypress	20.1%	27.7%	0.2%
Cypress-Water Tupelo	37.6%	11.1%	--
Pocosin & Bay Forest	11.8%	45.6%	3.6%
Miscellaneous	2.9%	1.0%	5.9%
Upland	24.5%	1.0%	9.9%
TOTAL	100.0%	100.0%	100.0%

1 Foul zone and 6 foot contour not indicated on all maps. Percentage of total points where data are available is indicated in parentheses.

to the nearest upland (Table 2). Exposure of Albemarle South shorelines was strongly oriented toward the north (5.9), while Alligator River was oriented only slightly north (1.1) and Pamlico North slightly south (0.87). Average fetch was least for the Alligator River (4.4 km) due to its narrow width, and approximately 10 km for the other two areas. The most frequent fetch interval for Albemarle South was in the 8 - 12 km range, while Pamlico North had a number of fetches larger than 20 km (Figure 5). Width of the zone between the shoreline and the 6 foot water depth contour was least for Alligator River (482 m) and progressively greater for Albemarle South and Pamlico North (Figure 6). Average distance to upland was least for Albemarle South (658 m) and nearly twice that or greater for the other two sites. The frequency distributions show that a majority of the uplands for Albemarle South were less than 1 km (72%) from the shoreline while the majority of uplands were greater than 2 km from the shoreline for the other two sites (Figure 7).

Fringe wetland vegetation cover varied greatly among the three regions (Table 2). Albemarle South was dominated by cypress-water tupelo forests with lesser amounts of maple-gum-cypress and pocosin and bay forest vegetation. Alligator River departed from the other areas by having a large proportion of pocosin and bay forest (45.6%), although maple-gum-cypress and cypress-water tupelo together comprised 38.8% of the wetland shoreline. In contrast, Pamlico North is mostly brackish marsh

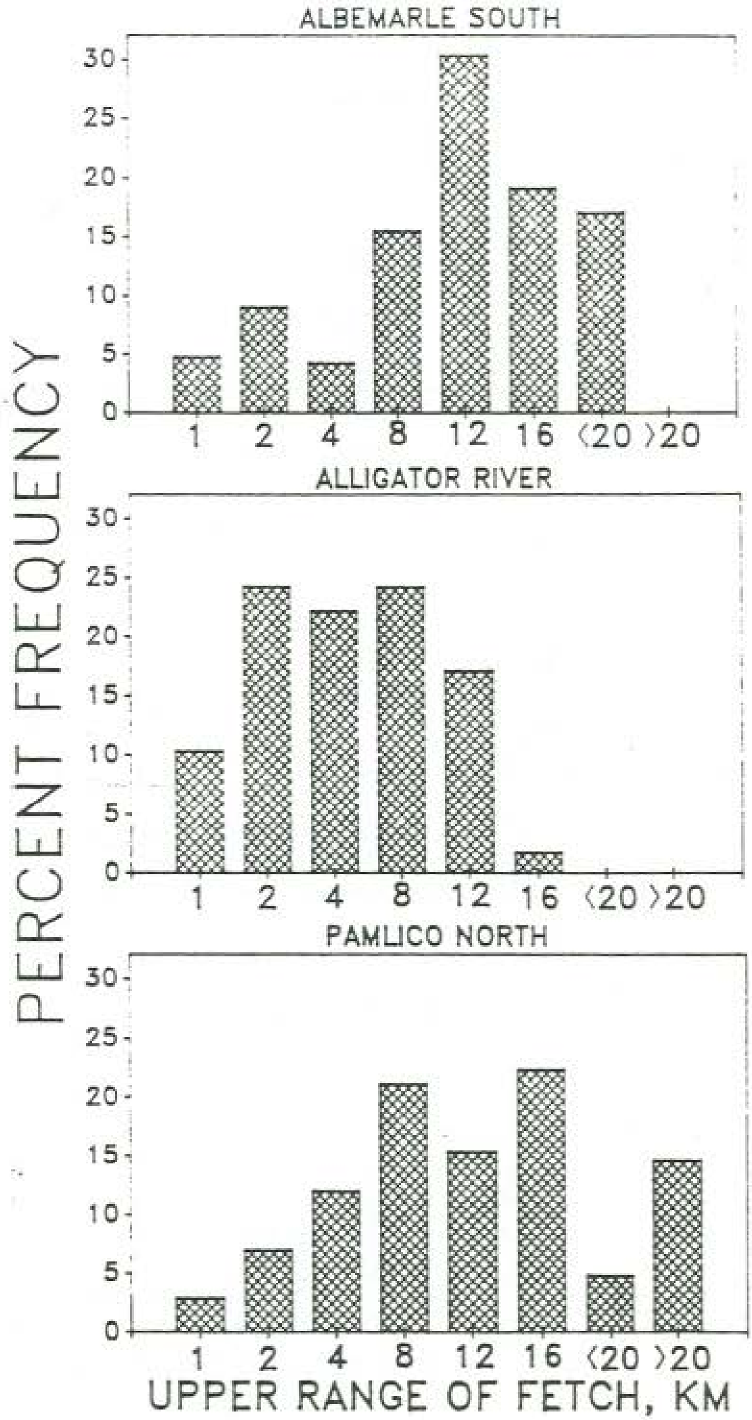


Figure 5. Frequency distribution of fetch for Albemarle South, Alligator River, and Pamlico North.

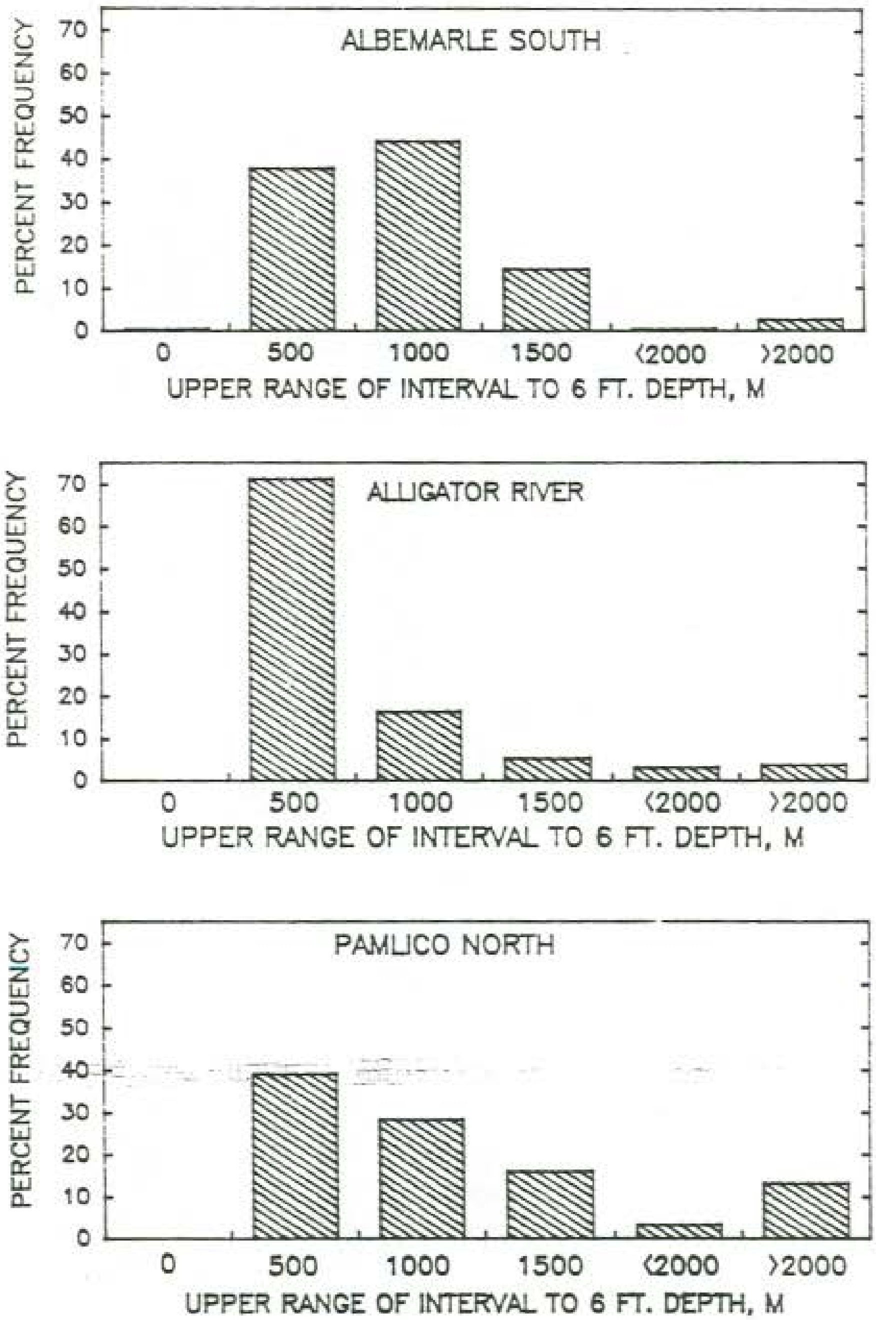


Figure 6. Frequency distribution of distance from shoreline to 6 foot depth contour for Albemarle South, Alligator River, and Pamlico North.

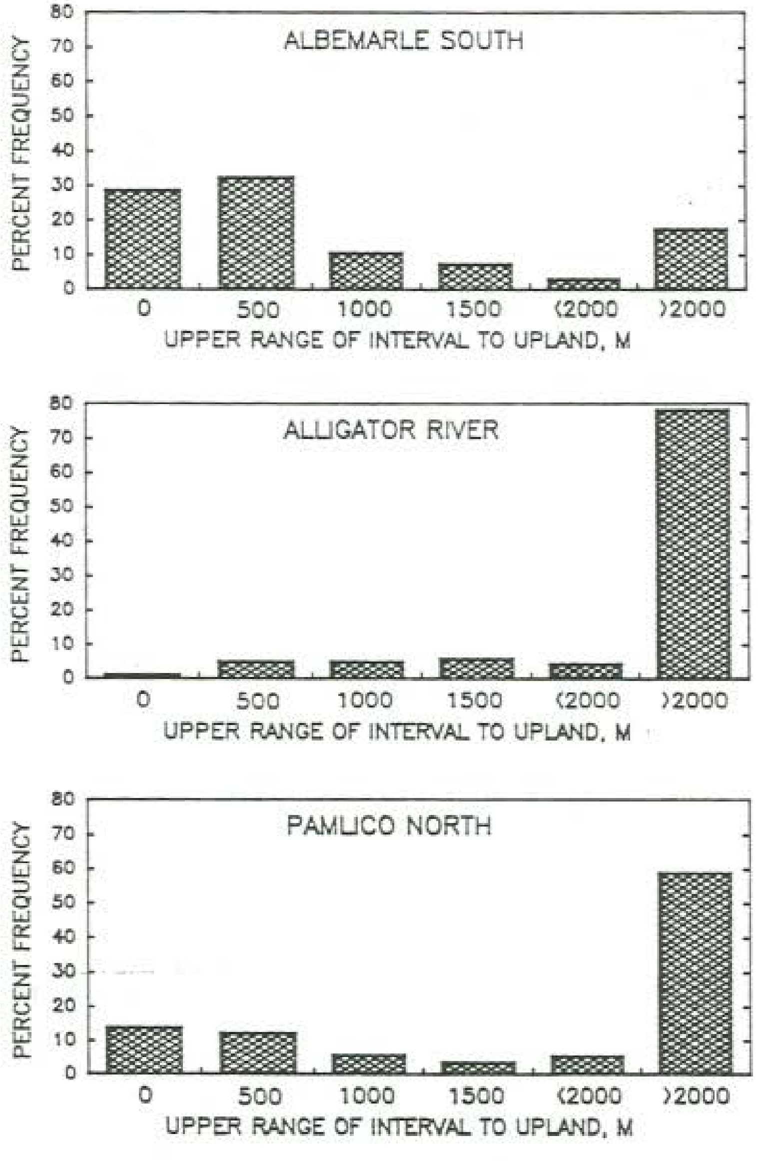


Figure 7. Frequency distribution of distance from shoreline to nearest upland site for Albemarle South, Alligator River, and Pamlico North.

(65.3%) and marsh shrub transition (14.4%). Forested wetlands as a fringe feature are rare along this reach. Appendix B lists the NWI types that were aggregated into these categories of vegetation.

Description of Fringe Swamps

Chowan River

Nyssa sylvatica var. biflora (henceforth reported as N. sylvatica) and Fraxinus sp. dominated the shoreline plot (Table 3). In the intermediate plot Acer rubrum was codominant with the same two species. At the interior plot Fraxinus sp. was absent, resulting in strong dominance by N. sylvatica subdominance by Acer rubrum. Density of live trees at the shoreline (2450/ha) was similar to the intermediate plot (2525/ha) and both were considerably higher than the interior plot (1475/ha). Basal area of live trees progressively decreased from shoreline (60 m^2/ha) to the interior (26 m^2/ha). The transition from shoreline to intermediate to interior plots can be typified as N. sylvatica-Fraxinus sp. of high density and basal area at the shoreline, followed by N. sylvatica-A. rubrum of high density and moderate basal area at the intermediate site, and finally N. sylvatica-A. rubrum of moderate density and basal area at the interior site (Figure 8). The intermediate site differed from the others in having a more even distribution of species (Figure 8) and fewer dead trees as indicated by the high live/dead ratio (51) in comparison with the other sites (only 4) (Table 3). The offshore fragment with permanent flooding had a disproportionately high basal area for such a low density, the result of a few very large trees. The high DBH of individuals is a consequence of more rapid growth of the lower trunk associated with long hydroperiod. Nyssa aquatica and Taxodium distichum dominated this plot, two species that were of minor importance or lacking in the other plots.

Spatial heterogeneity within the subplots of the 20 m x 20 m plot varied according to the measurement (Table 4). Variation in density was relatively low with the highest value being 47% higher than the lowest value. The highest basal area was 86% greater than the lowest. Dead tree density varied over a four-fold range, while dead tree basal area varied over an 11-fold range. The number of species ranged from a low of 5 to a high of 8. Most of these were represented by only one or two individuals which suggests that plot sizes were too small to draw conclusions about species diversity.

During our visits in May 1988, we noticed that many of the trees in the stand were defoliated. The caterpillar, Malacosoma disstria Hub., apparently was responsible. Specimens were sent

Table 3. Vegetation structure of Chowan River site. Plot sizes were 0.04 ha unless otherwise indicated. Dead trees weren't identified.

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
SHORELINE (0-20 m)						
Living Trees						
Nyssa sylvatica	26	650	37.53	26.5	62.9	44.7
Fraxinus sp.	45	1125	14.95	45.9	25.1	35.5
Nyssa aquatica	5	125	5.47	5.1	9.2	7.1
Acer rubrum	8	200	1.25	8.2	2.1	5.1
Ilex verticillata	8	200	0.29	8.2	0.5	4.3
Cornus stricta	2	50	0.03	2.0	0.0	1.0
Liquidambar styraciflua	1	25	0.06	1.0	0.1	0.6
Ilex opaca	1	25	0.04	1.0	0.1	0.5
Azalea viscosa	1	25	0.03	1.0	0.1	0.5
Alnus serrulata	1	25	0.02	1.0	0.0	0.5
TOTAL	98	2450	59.66	100.0	100.0	100.0
Dead Trees	22	550	3.25			
Live plus Dead	120	3000	62.91			
Ratio Live/Dead	4.5					
INTERMEDIATE (100-120 m)						
Living Trees						
Fraxinus sp.	10	250	2.39	9.9	6.5	8.2
Nyssa sylvatica	20	500	15.72	19.8	42.7	31.3
Taxodium distichum	6	150	9.91	5.9	26.9	16.4
Vaccinium corymbosum	1	25	0.02	1.0	0.1	0.5
Ilex opaca	3	75	0.15	3.0	0.4	1.7
Ilex verticillata	2	50	0.03	2.0	0.1	1.0
Persea borbonia	7	175	1.65	6.9	4.5	5.7
Acer rubrum	46	1150	4.44	45.5	12.1	28.8
Liquidambar styraciflua	4	100	1.14	4.0	3.1	3.5
Nyssa aquatica	2	50	1.32	2.0	3.6	2.8
TOTAL	101	2525	36.78	100.0	100.0	100.0
Dead Trees	2	50	0.18			
Live plus Dead	103	2575	36.95			
Ratio Live/Dead	51					

(Continued)

Table 3. Chowan River, continued.

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
INTERIOR (200-220 m)						
Living Trees						
<u>Nyssa</u> <u>sylvatica</u>	28	700	19.45	47.5	73.7	60.6
<u>Taxodium</u> <u>distichum</u>	1	25	2.18	1.7	8.2	5.0
<u>Ilex</u> <u>opaca</u>	4	100	0.11	6.8	0.4	3.6
<u>Ilex</u> <u>verticillata</u>	2	50	0.04	3.4	0.1	1.8
<u>Persea</u> <u>borbonia</u>	3	75	0.24	0.5	0.9	3.0
<u>Acer</u> <u>rubrum</u>	19	475	4.36	32.2	16.5	24.4
<u>Liquidambar</u> <u>styraciflua</u>	2	50	0.04	3.4	0.1	1.8
TOTAL	59	1475	26.40	100.0	100.0	100.0
Dead Trees	14	350	8.38			
Live plus Dead	73	1825	34.79			
Ratio Live/Dead	4.21					
OFFSHORE FRAGMENT, INTERMITTENT FLOODING (0.017 ha)						
Living Trees						
<u>Nyssa</u> <u>sylvatica</u>	9	529	40.05	18.4	55.3	36.8
<u>Fraxinus</u> sp.	23	1353	13.50	46.9	18.6	32.8
<u>Acer</u> <u>rubrum</u>	6	353	3.69	12.2	5.1	8.7
<u>Nyssa</u> <u>aquatica</u>	3	176	7.07	6.1	9.8	7.9
<u>Taxodium</u> <u>distichum</u>	1	59	7.47	2.0	10.3	6.2
<u>Ilex</u> <u>opaca</u>	2	118	0.22	4.1	0.3	2.2
<u>Ilex</u> <u>verticillata</u>	2	118	0.20	4.1	0.3	2.2
<u>Vaccinium</u> <u>corymbosum</u>	2	118	0.06	4.1	0.1	2.1
<u>Liquidambar</u> <u>styraciflua</u>	1	59	0.17	2.0	0.2	1.1
Total	49	2882	72.42	100.0	100.0	100.0
Dead Trees	5	294	8.90			
Live plus Dead	54	3176	81.32			
Ratio Live/Dead	9.8					

Table 3. Chowan River, concluded.

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
OFFSHORE FRAGMENT, PERMANENT FLOODING (0.032 ha)						
Living Trees						
Nyssa aquatica	6	188	21.65	24.0	43.6	33.8
Taxodium distichum	3	94	16.71	12.0	33.6	22.8
Nyssa sylvatica	5	156	9.86	20.0	19.9	19.9
Fraxinus sp.	3	94	1.07	12.0	2.2	7.1
Ilex verticillata	3	94	0.15	12.0	0.3	6.2
Cyrilla racemiflora	3	94	0.06	12.0	0.1	6.1
Acer rubrum	2	63	0.17	8.0	0.3	4.2
Total	25	781	49.68	100.0	100.0	100.0
Dead Trees	8	250	4.30			
Live plus Dead	33	1031	53.99			
Ratio Live/Dead	3.1					

Table 4. Comparison of 10 x 10 m subplots at Chowan River site.

	Density per 10 m x 10 m plot				Basal area (m^2/hectare)			
	0-10N	0-10S	10-20S	10-20N	0-10N	0-10S	10-20S	10-20N
Fraxinus sp.	14	13	13	5	24.57	14.96	16.74	3.54
Nyssa sylvatica	1	10	2	13	14.52	44.46	14.74	76.41
Acer rubrum	2	2	1	3	2.46	0.69	1.02	0.82
Nyssa aquatica	1	1	3	--	1.41	7.60	12.87	---
Alnus serrulata	1	--	--	--	0.07	---	---	---
Ilex opaca	1	--	--	--	0.16	---	---	---
Ilex verticillata	1	4	2	1	0.44	0.31	0.22	0.18
Cornus stricta	1	--	--	1	0.05	---	---	0.07
Azalea viscosa	--	1	--	--	---	0.13	---	---
Liquidambar styraciflua	--	--	--	1	---	---	---	0.22
Total live	22	31	21	24	43.69	68.14	45.59	81.23
Dead	2	5	8	7	0.65	4.32	7.23	0.82

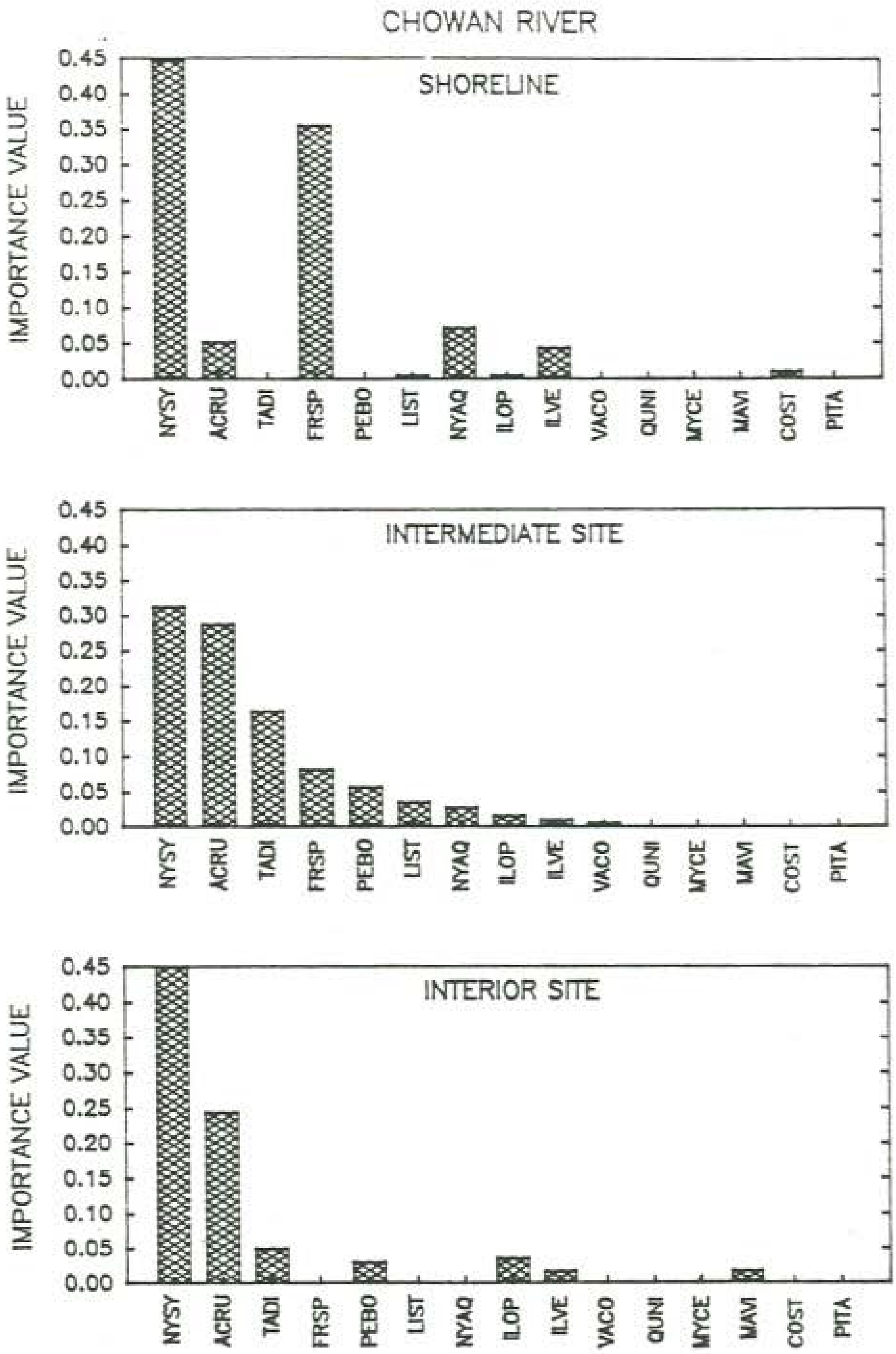


Figure 8. Importance values of woody species at Chowan River site. Species codes are NYSY = *Nyssa sylvatica* var. *biflora* (swamp blackgum), ACRU = *Acer rubrum* (red maple), TADI = *Taxodium distichlis* (bald cypress), FRSP = *Fraxinus* sp. (ash), PEBO = *Persea borbonia* (red bay), LIST = *Liquidambar styraciflua* (sweetgum), NYAQ = *Nyssa aquatica* (water tupelo), ILOP = *Ilex opaca* (American holly), ILVE = *Ilex verticillata* (black alder), VACO = *Vaccinium corymbosum* (highbush blueberry), QUNI = *Quercus nigra* (water oak), MYCI = *Myrica cerifera* (wax myrtle), MAVI = *Magnolia virginiana* (sweet bay), COST = *Cornus stricta* (swamp dogwood), PITA = *Pinus taeda* (loblolly pine).

to William Conner at the Center for Wetlands at Louisiana State University to confirm identification. The phenomenon in *Nyssa aquatica* forests in Louisiana is quite common (Rejmánek et al. 1987).

Grapevine Landing

Nyssa sylvatica and *A. rubrum* dominated the shoreline site (Table 5), and *Liquidambar styraciflua* ranked third in importance. In the intermediate plot *L. styraciflua* and *N. sylvatica* were codominant while *Quercus nigra* and *A. rubrum* made lesser but significant contributions to the community composition. At the interior site, highest importance was *L. styraciflua*, but four other species (*Myrica cerifera*, *A. rubrum*, *N. sylvatica*, *Persea borbonia*) contributed 57% of the total importance. Structural measurements were very similar in all three sites. Density ranged between 2300 and 2975/ha, basal area between 31 and 36 m^2/ha, and ratios of live to dead trees between 3 and 5. Overall, there were fairly minor changes in species composition, while shifts in dominance were responsible for most of the differences (Figure 9). For example, *M. cerifera* and *P. borbonia*, which normally are minor understory species in well developed forests, contributed proportionately more structurally to the interior site than the other two sites. The lack of clear dominance of canopy species toward the interior may be indicative of recent disturbance by logging of the larger trees. The high density of the offshore fragment was due in part to the relatively large number of *M. cerifera* growing along the unshaded shoreline.

Poplar Point

Although *A. rubrum* contributed most to the shoreline site, *M. cerifera*, *P. borbonia*, and *L. styraciflua* also made important contributions to community structure (Table 6). *Taxodium distichum* was limited to this site and the 0.014 ha peninsula that projected from the shoreline. The intermediate site differed by a greater contribution from *N. sylvatica* and lesser contribution from *M. cerifera*. The interior site departed markedly from the other plots by being dominated by *P. borbonia*. Densities were relatively high (>2500/ha) at all sites, and especially high (4850/ha) at the intermediate site owing to a large number of *A. rubrum*. Basal areas were moderate at the shoreline plot (27 m^2/ha) and the intermediate plot (35 m^2/ha), but much lower at the interior plot (19 m^2/ha). Ratios of live to dead trees showed no explainable pattern, and ranged between 4 and 10. The overall pattern was one of *A. rubrum* dominance at the shoreline and intermediate sites, while the interior site was dominated by *P. borbonia* and had much lower basal area (Figure 10).

Table 5. Vegetation structure of Grapevine Landing site on the Alligator River. Plot sizes were 0.04 ha unless otherwise indicated.

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
SHORELINE (0-20 m)						
Living Trees						
Nyssa sylvatica	54	1350	14.18	47.0	44.5	45.7
Acer rubrum	26	650	6.71	22.6	21.1	21.8
Liquidambar styraciflua	8	200	6.38	7.0	20.0	13.5
Quercus nigra	7	175	2.23	6.1	7.0	6.6
Magnolia virginiana	8	200	1.36	7.0	4.3	5.6
Persea borbonia	6	150	0.52	5.2	1.6	3.4
Pinus taeda	3	75	0.28	2.6	0.9	1.7
Myrica cerifera	1	25	0.13	0.9	0.4	0.6
Ilex opaca	1	25	0.03	0.9	0.1	0.5
Vaccinium corymbosum	1	25	0.02	0.9	0.1	0.5
TOTAL	115	2875	31.84	100.0	100.0	100.0
Dead Trees	29	725	4.48			
Live plus Dead	144	3600	36.32			
Ratio Live/Dead	4.0					
INTERMEDIATE (120-140 m)						
Living Trees						
Liquidambar styraciflua	31	775	17.01	26.1	48.0	37.0
Nyssa sylvatica	40	1000	8.99	33.6	25.4	29.5
Quercus nigra	9	225	6.24	7.6	17.6	12.6
Acer rubrum	23	575	1.95	19.3	5.5	12.4
Myrica cerifera	7	175	0.48	5.9	1.3	3.6
Persea borbonia	5	125	0.49	4.2	1.4	2.8
Magnolia virginiana	3	75	0.18	2.5	0.5	1.5
Taxodium distichum	1	25	0.12	0.8	0.3	0.6
Total	119	2975	35.45	100.0	100.0	100.0
Dead Trees	27	675	3.30			
Live plus Dead	146	3650	38.76			
Ratio Live/Dead	4.4					

(Continued)

Table 5. Grapevine Landing, concluded.

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
INTERIOR (220-240 m)						
Living Trees						
Liquidambar styraciflua	17	425	13.59	18.5	38.3	28.4
Myrica cerifera	29	725	1.47	31.5	4.1	17.8
Acer rubrum	12	300	5.72	13.0	16.1	14.6
Nyssa sylvatica	11	275	5.43	12.0	15.3	13.6
Persea borbonia	14	350	2.48	15.2	7.0	11.1
Quercus nigra	6	150	2.54	6.5	7.2	6.8
Pinus taeda	1	25	4.19	1.1	11.8	6.4
Ilex opaca	1	25	0.09	1.1	0.2	0.7
Vaccinium corymbosum	1	25	0.02	1.1	0.0	0.6
TOTAL	92	2300	35.52	100.0	100.0	100.0
Dead Trees	30	750	0.11			
Live plus Dead	122	3050	35.63			
Ratio Live/Dead	3.1					

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
OFFSHORE FRAGMENT OF PLOT (0.004 ha)						
Living Trees						
Nyssa sylvatica	6	1500	18.24	33.3	44.1	38.7
Taxodium distichum	2	500	18.95	11.1	45.8	28.5
Myrica cerifera	5	1250	2.24	27.8	5.4	16.6
Pinus taeda	3	750	0.82	16.7	2.0	9.3
Persea borbonia	2	500	1.12	11.1	2.7	6.9
TOTAL	18	4500	41.37	100.0	100.0	100.0
Dead Trees	12	3000	43.74			
Live plus Dead	30	7500	85.10			
Ratio Live/Dead	1.5					

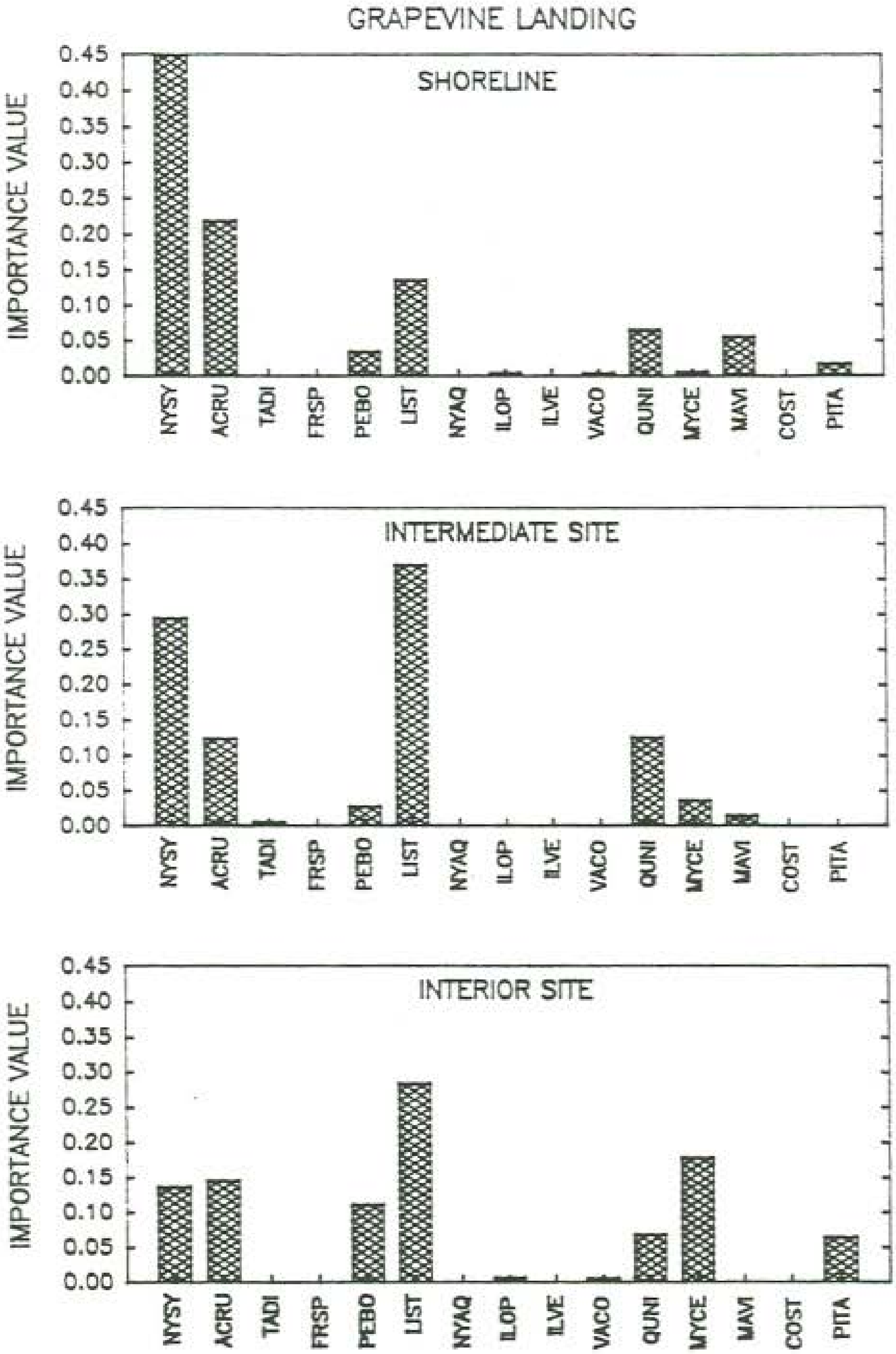


Figure 9. Importance values of woody species at Grapevine Landing site. Species codes are given in legend of Figure 8.

Table 6. Vegetation structure of Poplar Point site on the Alligator River. Plot sizes were 0.04 ha unless otherwise indicated.

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
SHORELINE (0-20 m)						
Acer rubrum	43	1075	8.37	42.2	30.7	36.4
Myrica cerifera	11	275	6.12	10.8	22.5	16.6
Persea borbonia	24	600	2.00	23.5	7.3	15.4
Liquidambar styraciflua	15	375	2.83	14.7	10.4	12.6
Taxodium distichum	3	75	3.46	2.9	12.7	7.8
Nyssa sylvatica	3	75	2.17	2.9	8.0	5.5
Pinus taeda	2	50	2.22	2.0	8.2	5.1
Magnolia virginiana	1	25	0.06	1.0	0.2	0.6
Total	102	2550	27.23	100.0	100.0	100.0
Dead Trees	24	600	6.12			
Live plus Dead	126	3150	33.36			
Ratio Live/Dead	4.3					
INTERMEDIATE (140-160 m)						
Acer rubrum	128	3200	9.04	66.0	25.9	46.0
Persea borbonia	28	700	11.69	14.4	33.6	24.0
Nyssa sylvatica	5	125	8.47	2.6	24.3	13.4
Liquidambar styraciflua	19	475	5.04	9.8	14.5	12.1
Myrica cerifera	13	325	0.51	6.7	1.5	4.1
Pinus serotina	1	25	0.09	0.5	0.3	0.4
Total	194	4850	34.84	100.0	100.0	100.0
Dead Trees	19	475	0.44			
Live plus Dead	213	5325	35.28			
Ratio Live/Dead	10					

(Continued)

Table 6. Poplar Point, concluded.

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
INTERIOR (280-300 m)						
Living Trees:						
<u>Persea borbonia</u>	50	1250	11.145	41.3	60.1	50.7
<u>Acer rubrum</u>	26	650	3.901	21.5	21.0	21.3
<u>Ilex verticillata</u>	20	500	0.375	16.5	2.0	9.3
<u>Pinus taeda</u>	12	300	0.205	9.9	1.1	5.5
<u>Nyssa sylvatica</u>	2	50	1.597	1.7	8.6	5.1
<u>Magnolia virginiana</u>	3	75	1.052	2.5	5.7	4.1
<u>Vaccinium corymbosum</u>	5	125	0.114	4.1	0.6	2.4
<u>Myrica cerifera</u>	2	50	0.140	1.7	0.8	1.2
<u>Ilex opaca</u>	1	25	0.027	0.8	0.1	0.5
Total	121	3025	18.56	100.0	100.0	100.0
Dead Trees	14	350	3.57			
Live plus Dead	135	3375	22.12			
Ratio Live/Dead	8.6					

Location and Species	n	Density (n/ha)	Basal area (m^2/ha)	Relative density (%)	Relative density (%)	Importance value (%)
PARTIAL PLOT ON PENINSULA (0.014 ha)						
Living Trees						
<u>Taxodium distichum</u>	7	500	13.85	28.0	51.0	39.5
<u>Pinus taeda</u>	4	286	8.70	16.0	32.0	24.0
<u>Myrica cerifera</u>	6	429	0.76	24.0	2.8	13.4
<u>Persea borbonia</u>	4	286	1.88	16.0	6.9	11.5
<u>Acer rubrum</u>	3	214	1.54	12.0	5.7	8.8
<u>Nyssa sylvatica</u>	1	71	0.43	4.0	1.6	2.8
Total	25	1786	27.17	100.0	100.0	100.0
Dead Trees	21	1500	3.50			
Live plus Dead	46	3286	30.67			
Ratio Live/Dead	1.2					

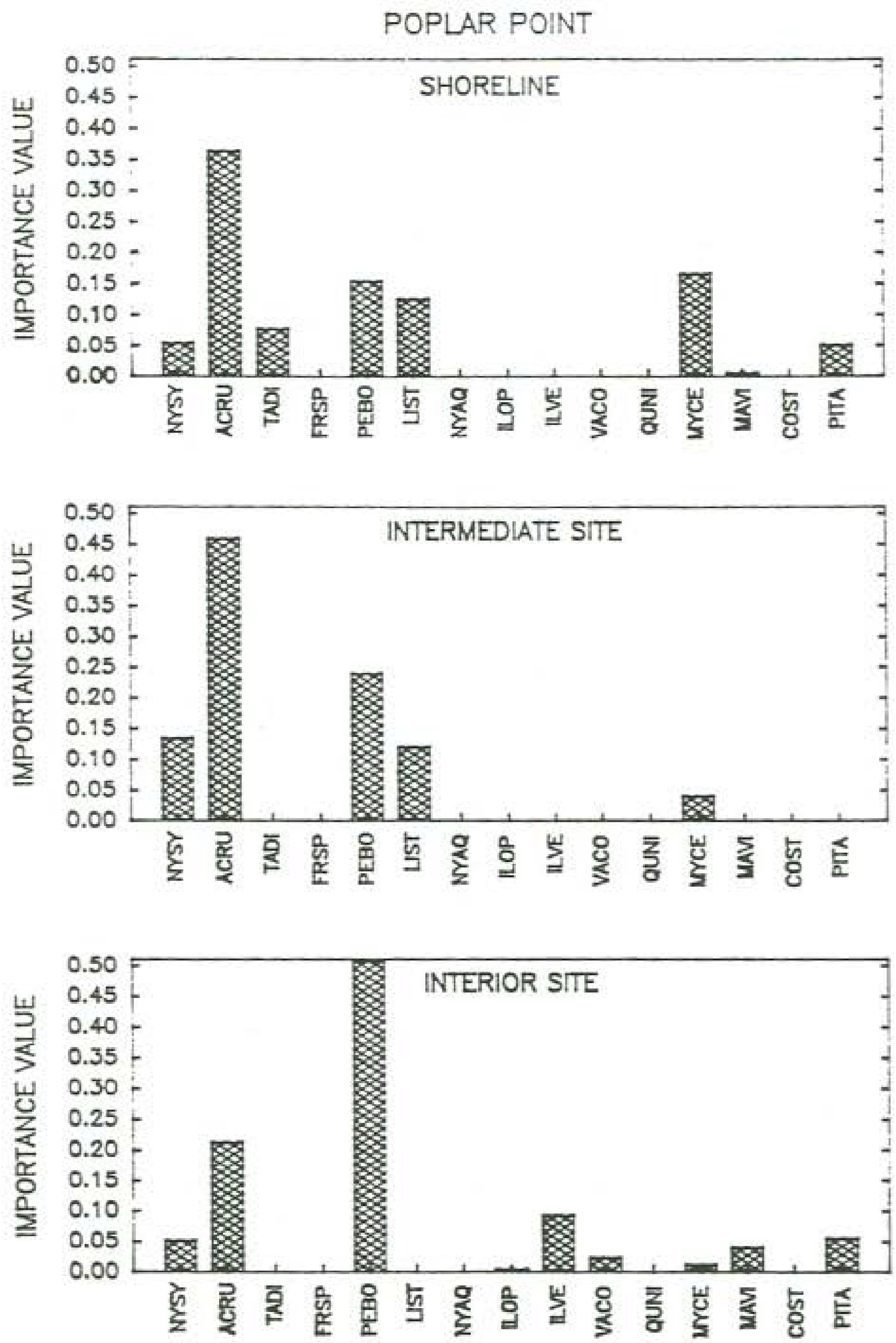


Figure 10. Importance values of woody species at Poplar Point site. Species codes are given in legend of Figure 8.

Size Class Distribution

Because of the small sample size, species were aggregated for examining size class distribution. Both live and dead trees showed an expected decrease in frequency with increasing size at all sites (Figure 11). There were some noteworthy patterns, however. The Chowan River and Grapevine Landing stands have much fewer stems in the small size classes than the Poplar Point stand. The shoreline site of the Chowan River had a greater proportion in the 28 cm to 32 cm size class than more interior sites. The virtual absence of dead trees at the intermediate site is distinct and is accompanied by a higher proportion of trees in the smaller size classes than at other sites. Grapevine Landing lacked distinctive features. Ratios of live to dead were nearly constant (Table 5); size classes of dead followed patterns of live. The shoreline stand at Poplar Point mimicked the curves of Grapevine Landing. However, the other sites at Poplar Point had strong representation of small size classes due to *Acer rubrum* at the intermediate site and *Persea borbonia* at the interior site (Table 6).

Elevation and Sediments

Elevations of the forest floor along transects at Grapevine Landing and Poplar Point are given relative to the water surface in the Alligator River at the time of measurement (Figure 12). At Grapevine Landing, the highest elevations were within the first 5 m of the shoreline. From about 10 m to 120 m the forest floor was relatively flat with little microtopographic variation. Thereafter, elevations toward the interior showed greater among-site variation. Microtopographic relief was greater in spite of efforts to avoid measuring elevations of hummocky surfaces of root masses and trunks of uprooted trees and stumps. At Poplar Point, the near-shore sites were elevated approximately the same relative to the interior but the zone of higher elevation was much broader than that at Grapevine Landing (Figure 12b). The interior portion of the Poplar Point transect was extremely uneven.

Sediments at the Chowan River site consisted mostly of peaty clays and clayey peats up to 3.2 m thick overlying a sandy base (Figure 13). From the shoreline to 80 m, there was a more gradual transition through a peaty sand layer between the clayey peat layers and basal sands below. The three most interior profiles had considerably deeper organic layers. At Grapevine Landing, profiles lacked textures indicative of high organic content. In fact, the relatively shallow layer (<1.2 m) of soft sediments overlaid dense sandy clay or clayey sand. Depths of clayey peat at the Poplar Point transect were generally deeper and more uniform than they are at the Chowan River site. From the shoreline

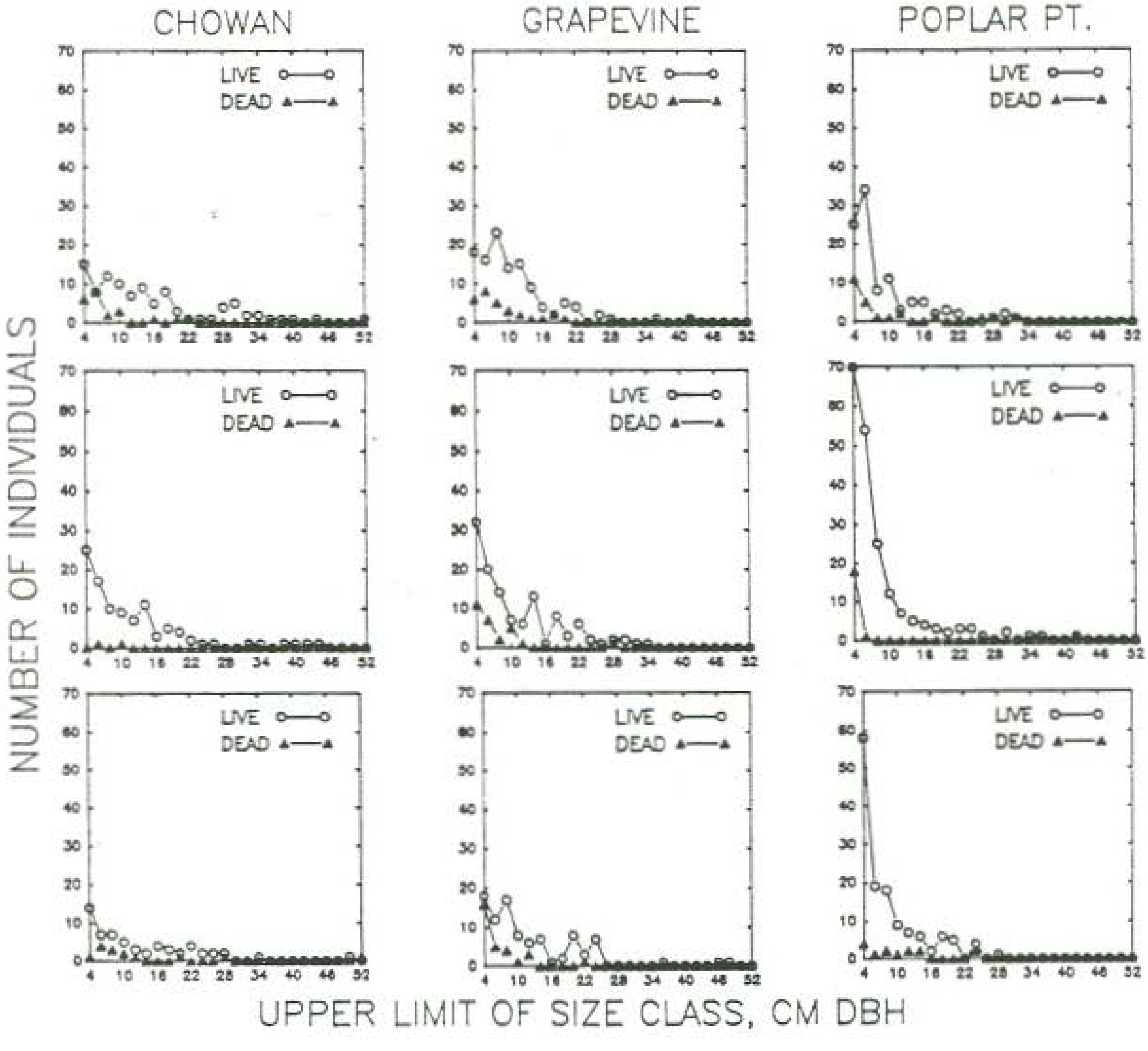


Figure 11. Size class distributions for live and dead trees, as proportion of total numbers for Chowan River, Grapevine Landing, and Poplar Point sites. Top panels are shoreline stands, bottom panels are interior stands, and middle panels are stands intermediate between shoreline and interior locations.

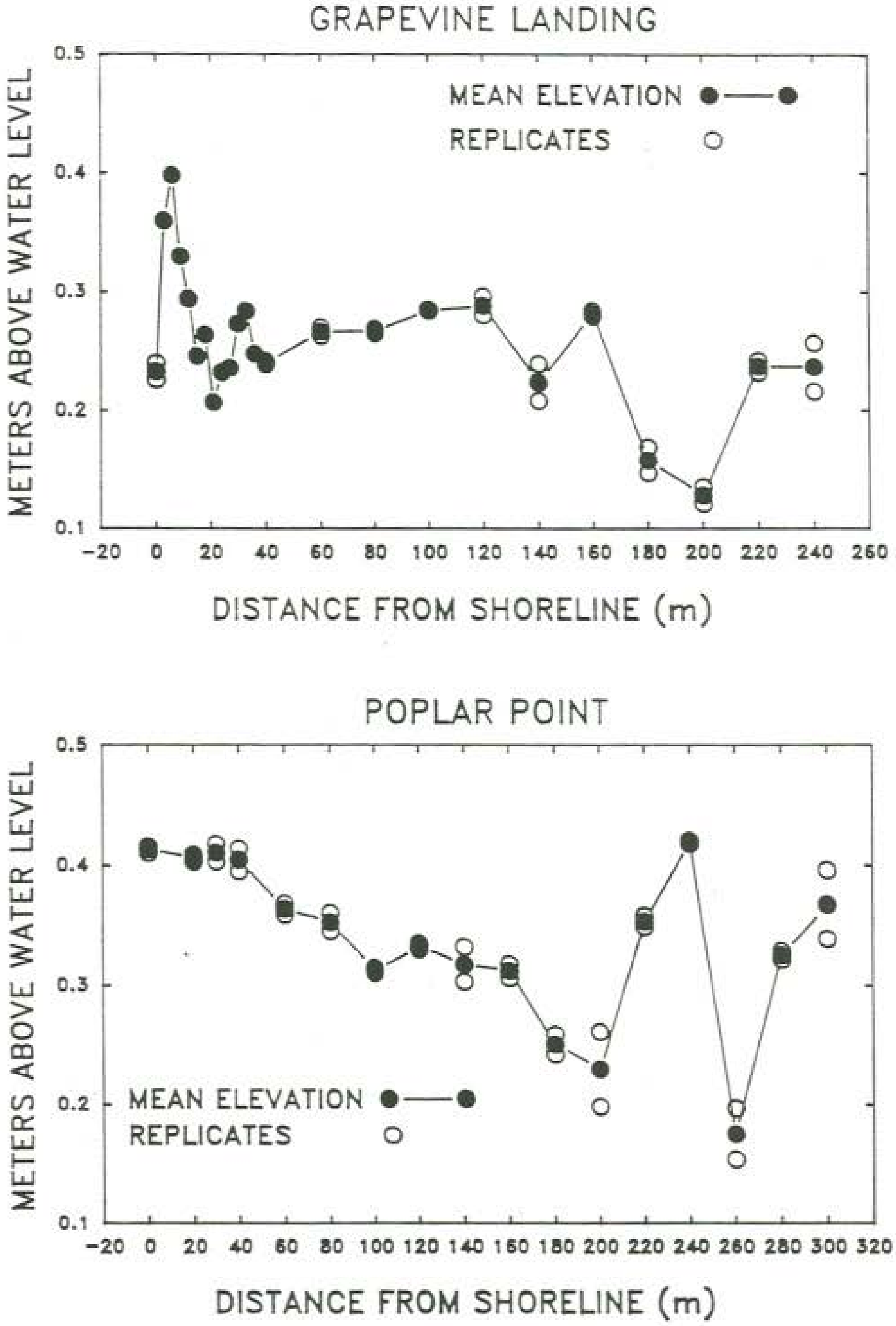


Figure 12. Elevation of Grapevine Landing and Poplar Point transects relative to water surface at the time of leveling.

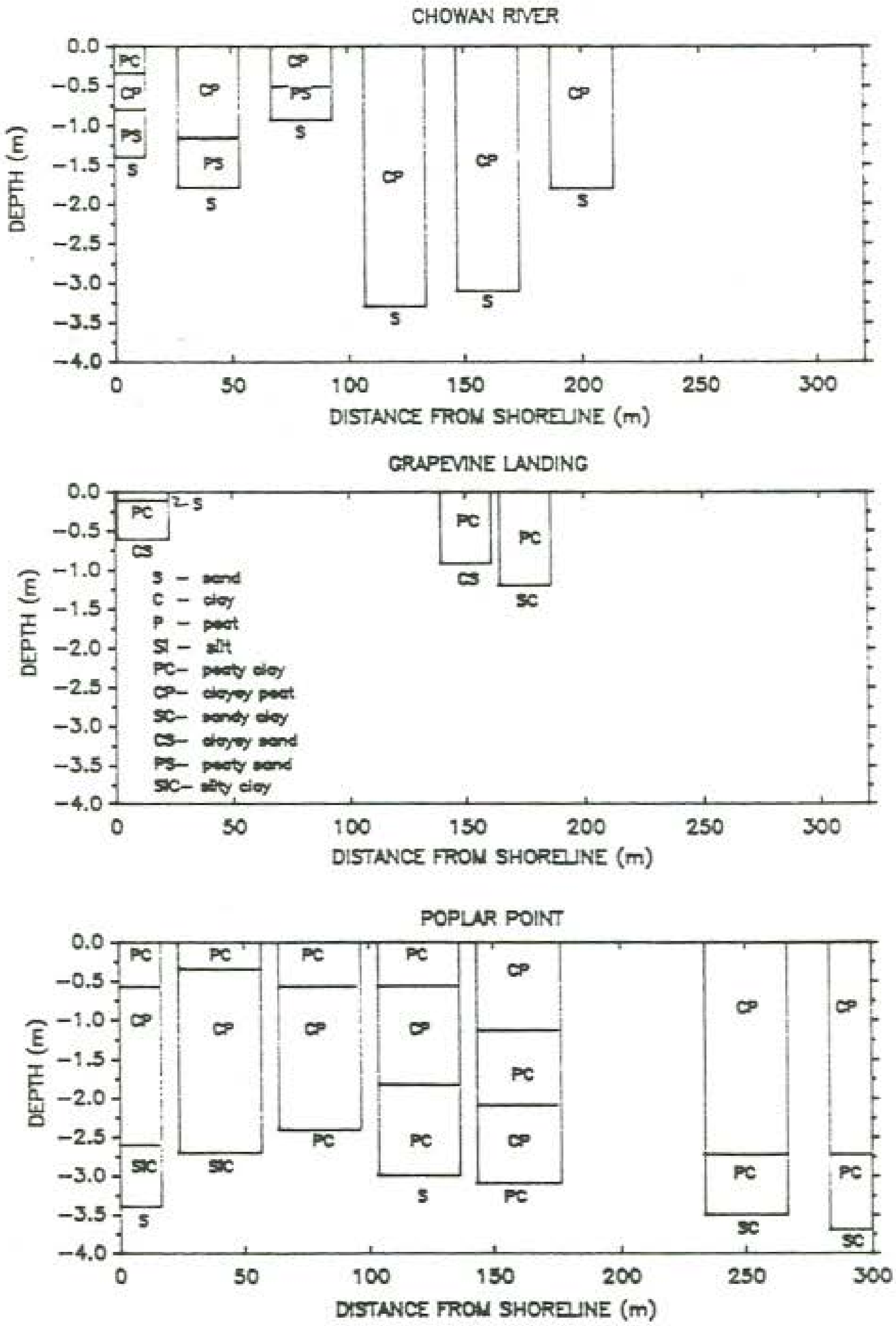


Figure 13. Depth distribution of sediment texture at Chowan River, Grapevine Landing, and Poplar Point sites.

to 120 m, there was a upper stratum of peaty clay of 0.3 to 0.6 m depth overlying a thicker, more organic layer. Whereas the Chowan River profiles ended in sand, the texture of basal deposits at Poplar Point ranged from sand to peaty clay. The two most interior profiles at Poplar Point had 2.7 m of continuous clayey peat.

Analysis of Flood Events

The three water level recorders at Rayes Beach on the Chowan River provide insight into the hydrologic characteristics of the swamp. They were located within the swamp at 45 m, 235 m, and 810 m from the shoreline. Water level fluctuations are potentially initiated by precipitation, overbank flooding from either headwater flooding or wind-induced flooding from the river, runoff and subsurface drainage, and evapotranspiration. Six events were chosen to illustrate these characteristics. Strong evidence of headwater flooding was provided by analysis of the data suggesting that the wetland was strongly riverine in this area of the Chowan River; apparently it is too isolated from Albemarle Sound to be classified as a fringe swamp. Nevertheless, results are reported in Appendix D.

DISCUSSION

The ecology of fringe wetlands cannot be addressed without taking into account issues of shoreline erosion, sea level rise, and society's response to these processes. Most of the emphasis in the past on shoreline processes has been oriented toward coastal beach erosion and management of the barrier islands (Godfrey 1976, Orford 1987, Bruun 1988), the importance of sediment sources and overwash processes in maintaining back-barrier marshes (Godfrey 1976, Hackney and Cleary 1987), and the stability of inlets (Fisher 1962). North Carolina's extensive barrier island system has provided the nation with a natural laboratory for understanding coastal processes (Dolan et al. 1980, Leatherman 1979, Pilkey and Davis 1987). By comparison, the even more extensive shorelines of the sounds and estuaries have been neglected, receiving only local attention primarily from the standpoint of shoreline erosion (Bellis et al. 1975, Stirewalt and Ingram 1974, USDA Soil Conservation Service 1975).

What has become apparent from this preliminary analysis is the extent to which entire landscapes in the coastal plain, rather than just shorelines, are currently under the influence of rising sea level. Wetlands have in the past and are currently playing a very important role in landscape level processes that affect hundreds of square kilometers of land. In contrast to other areas of the Atlantic coast where salt marshes are primarily affected by rising sea level, North Carolina is unique in the large amount of forested wetlands that fall into this category. The wetlands that are responding to rising sea level are among the least understood ecologically. The lack of appropriate models for predicting the effects of rising sea level, especially models that can accommodate the dominant landscape role that wetlands have played historically, has hindered progress in developing strategies for the management and protection of natural attributes of estuarine shorelines in North Carolina.

Regional Shoreline Characteristics

National Wetlands Inventory maps have been used to determine the amount of wetland surface area for a given geographic region such as by county, by state, or by drainage basin (e.g., Tiner 1986). The perspective used in this study was to selectively focus on the shoreline as an ecologically important landscape unit and sharp environmental transition. This entailed quantifying characteristics according to relative length of shoreline rather than by surface area, and was apparently a novel use of NWI maps (John Hefner, personal communication, Fish and Wildlife Service, Atlanta). From these data it is possible to assess the shoreline resource in terms of proportion of wetland versus upland, degree of zonation within a 200 m zone, exposure and orientation to wind and waves, and prevalence of vegetation types (Table 2).

What have we learned from this preliminary survey of estuarine shorelines? First, it is apparent that emergent wetlands dominate large portions of the shoreline. If wetlands are to be protected for their natural ecological attributes, then much of the shoreline surveyed is inappropriate for alternative uses (e.g., agricultural, residential, commercial, and urban development). While this is of no surprise to anyone familiar with the estuarine coast of North Carolina, the prevalence of wetlands over uplands for all three geographic regions emphasizes the need for a better understanding of the ecological, hydrological, and geological processes occurring in this transition zone. In the Alligator River, for example, 99 percent of the points sampled were classified as wetland, most of which were forested (Table 2). This would seem to strengthen arguments for allocating more of the area for its natural values. Much of the shoreline is already part of the Alligator River National Wildlife Refuge, and more of the surrounding shoreline falls within the acquisition plans of the Refuge (Robert Noffsinger, U.S. Fish and Wildlife Service, personal communication, 1988).

Second, we have learned that fringe wetlands of North Carolina's estuaries do not conform well to concepts developed for coastal wetlands elsewhere. In contrast to the model of a gradual elevational increase from marsh shoreline to upland, many of the fringe wetlands examined undergo no significant elevational change and do not undergo transition to uplands within a spatial scale that has any relevance to previous models. The spatial scale of the transition to upland (or lack of it) varies geographically. For example, the area designated as Albemarle South has most of its uplands within less than 500 m of the shoreline, while the other two geographic regions examined are dominated by a landscape in which upland is not encountered within 2 km distance (Figure 7). For this reason, alternative paradigms of response of landscapes to sea level rise need to be developed and are discussed below.

Some precautions are in order on the manner in which these results can be used. The results expressed as percent of shoreline give the probability that a given shoreline type occurs within a region rather than the exact distance covered by particular vegetation type. This is a subtle but important distinction because discrete points were used as the source of the information. Minimum mapping units for NWI maps are 1.0 acre (John Hefner, U.S. Fish and Wildlife Service, personal communication, Atlanta 1988) and thus they omit much of the environmental heterogeneity that would be recognized at a scale at which vegetation surveys are conducted on the ground. Therefore it would be inappropriate to estimate the number of kilometers of shoreline represented by brackish marsh in the Alligator River by multiplying the percentage of points of that category (6.5%) by the nominal shoreline length (169 km) (cf. Table 2). The 11 km of brackish marsh resulting from this calculation would represent a misuse of the data and could lead to erroneous interpretation. First, the points that had brackish marsh may also have had some other vegetation type as well within the 200 m distance, which is suggested in the average number of wetland types per point of 1.76 (Table 2). While it is ecologically more likely for brackish marsh to occur at the shoreline rather than landward of a forested wetland type, it would be necessary to consult the raw data for this information rather than the summary table. Second, the length of shoreline for the Alligator River is largely a function of scale of measurement. The nominal shoreline length reported in Table 2 is shorter by some unknown proportion than would have been determined either by planimetry of a map of the same scale or by a similar approach using a map of smaller scale (i.e., higher resolution). In summary, the analysis has provided insight into (1) differences in shorelines for large geographic areas and (2) information about the spatial relationships between wetlands and adjacent ecosystems. However, site-specific questions cannot be answered with data developed and analyzed at this scale or with these methods. In addition, only about 10% of the area of NWI maps have received ground truth verification.

Fringe Wetlands as Ecological and Hydrological Units

Hydrologic studies are lacking to provide the data necessary to estimate the width and boundary conditions of fringe wetlands in North Carolina's sounds and estuaries. Choice of a width may be a function of the processes of interest. Hydrology and associated geochemical and geomorphic factors are generally regarded as major variables that control wetland ecosystem structure and function. As hydrologic energy diminishes from the shoreline to the wetland interior, one might expect a corresponding change in hydrologic flushing, sediment dynamics, and plant species composition to a point that the wetland is indistinguishable from strictly interior wetlands (i.e., basin or depression wetlands, sensu Brinson 1988, Lugo et al. 1988) in which the hydrology is under predominately atmospheric controls of precipitation and evapotranspiration. In Cedar Island marsh where 2 years of continuous water table fluctuation were collected, precipitation and flooding from the estuary contributed about equally to water table fluctuations at a distance of 800 m from the shoreline (Brinson et al. in press b).

For the forested wetlands examined in this study, transitions from edge to interior are very subtle. The eroded, permanently flooded region at the shoreline and the storm levee are both good evidence of the hydrodynamic influence of the estuary. Where the fringe forest migrates into a short pocosin peatland, the boundary would be more evident because of contrasting vegetation stature than if the migration were into a gum-maple swamp growing on inorganic sediment. The influence of shoreline processes and hence influence on the fringe zone appears to occur within the first 200 to 300 m. This does not mean, however, that all hydrologic influences of the larger body of water are absent further inland. More information than available in this preliminary analysis will be required to refine the hydrologic properties of this zone.

Even if it were possible to establish interior boundaries of the fringe wetland zone for the purpose of calculating its surface area, the exercise might be missing an essential point of the function of this wetland type. First, emphasis on surface area is misplaced because it is the length of the ecosystem rather than its width or surface area that represents the ecologically important dimension. Second, fringe wetlands would be expected to represent a small percentage of surface area relative to other ecosystems. Because of their boundary position between two contrasting environments (aquatic versus terrestrial or basin wetland), surface area would not be an ecologically meaningful parameter with which to judge their importance. By analogy, statistics given for beach surface area rather than length for North Carolina's Outer Banks would tend to minimize their importance as a natural resource.

The outer eroding portion of fringe swamps has a great deal of habitat complexity as revealed by fallen logs, exposed roots, and sheltered areas (Blanck 1980). Beds of Nuphar luteum occur in the shallow waters protected by trees (Twilley et al. 1985). Erosion, and possibly rising sea level, is likely a necessary condition to maintain this complexity. In other words, a perpetual state of change (i.e., erosion) is necessary to maintain the shoreline in its present condition.

Table 7 compares structure and dominant species of the three sites in this study with two sites in South Creek (Brinson et al. 1985). (Two of the sites from South Creek that had been affected by salinity stress were omitted from the comparison.) The similarities are more striking than the differences. The site that departs most from the others in species composition and density is the JB-4 site at South Creek which is above the influence of rising sea level and is thus better drained. While all of these plots have likely been exposed to timber harvest and perhaps other disturbances, the size class distributions that group all species do not provide great insight into whether the stands are in either an extreme senescent or youthful condition. The intermediate and interior sites at Poplar Point, however, have

Table 7. Comparison of community structure and dominant species of three sites in this study with those in South Creek (Brinson et al. 1985). Sites from this study represent the average of three 20 m x 20 m plots.

	This study			South Creek	
	Chowan	Grapevine	Poplar Pt	JK-3	JB-4
Density (n/ha)					
Living	2150	2717	3475	2450	1350
Dead	317	717	475	430	220
Ratio living to dead	6.8	3.8	7.3	5.7	6.1
Basal area (m^2/ha)					
Living	40.9	34.3	26.9	48.1	31.9
Dead	3.9	2.6	3.4	2.4	2.0
Ratio living to dead	10.4	13.2	8	20	16
Highest Importance Values					
First	*Nyssa sylvatica*	*Nyssa sylvatica*	*Acer rubrum*	*Nyssa sylvatica*	*Fraxinus* spp.
Second	*Fraxinus* spp.	*Liquidambar styraciflua*	*Persea borbonia*	*Fraxinus* spp.	*Acer rubrum*
Third	*Acer rubrum*	*Acer rubrum*	*L. styraciflua*	*Acer rubrum*	*Ulmus* spp.
Fourth	*Nyssa aquatica*	*Myrica cerifera*	*Nyssa sylvatica*	*Carpinus caroliniana*	*L. styraciflua*

large numbers in the smallest size classes and very few dead stems, both of which could result from recent disturbance. Sizes of plots were considered too small to make generalizations about species richness of these forest types. Greater replication, an unbiased approach toward site selection, and aging of trees would be needed to generalize results to larger geographic areas.

Sea Level Rise, Fringe Wetlands, and Landscape Response

The rate of sea-level rise is projected to increase within the next few decades (Titus 1988b). Fringe wetlands as well as those located further inland in the study area have been under the influence of this rise in recent geologic history. Consequently, it is relevant to ask what insight the current study might provide into questions about the effect of sea-level rise on wetlands of the region.

Two existing "models" or approaches for predicting effects of sea-level rise on wetlands are commonly applied to coastal fringe marshes in North Carolina. The first predictive approach is to estimate the location of future shorelines based on topographic information. In this procedure, elevation contour lines on topographic maps are used to establish the boundary between water and land if sea level should rise to the same level as the contour. The approach can be made slightly more sophisticated by invoking an estimate of shoreline recession rate. What seems like a straightforward approach unfortunately ignores the geologic role that wetlands have played in landscape maintenance and development in the coastal plain during the Holocene. Dare County, where part of this study took place, provides a good example of the fallacy of the approach. If sea level rose by an additional 1 m, virtually the whole county would be submerged. A similar conclusion would have been reached if the projection had been made a thousand years ago when sea level was at least 1 m below the present level (Gornitz et al. 1982). The reason that Dare County did not disappear under water was that wetlands, through the accumulation of organic and inorganic sediments, have been able to maintain an emergent condition rather than being submerged by rising water levels in the estuary. Average distance to upland from shorelines in Alligator River and Pamlico North regions are 1.8 and 1.2 km, respectively (Table 2). As both of these geographic regions are partly in Dare County, the long distances to upland underscore the extent to which wetlands dominate the landscape of Dare County. (The distances are actually underestimates because distances greater than 2.0 km were incorporated in the averages as 2.0 km.) By the same token, if sea level should continue to rise another 1.0 m at present rates, we should not expect low-lying areas to become submerged. The transformation of land to open water occurs by shoreline erosion rather than through submergence.

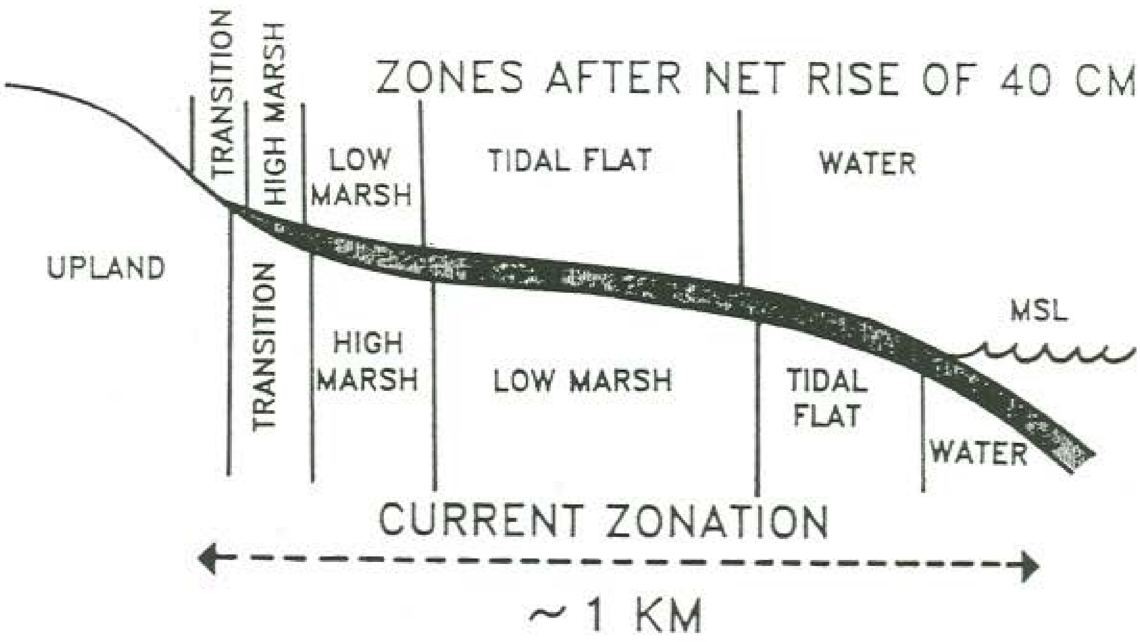
The second model depicts marshes migrating upward and inland in response to sea-level rise. According to Titus (1988a):

> "The net change in total marsh acreage depends on the slopes of the marsh and upland areas. If the land has a constant slope throughout the marsh and upland, then the area lost to marsh drowning will be equal to the area gained by the landward encroachment of spring high tides. In most areas, however, the slope above the marsh is steeper than the marsh; so a rise in sea level causes a net loss of marsh acreage."

During the initial reconnaissance we found that sloping wetlands and gradual transitions to uplands were uncharacteristic of the region. If there is a slope to these wetlands, it is probably more a function of large scale peat building processes similar to that which results in raised bogs rather than control by underlying topography (Clymo 1984). For example, Cedar Island marsh increases in elevation approximately 15 - 20 cm from just inside the storm levee to the center of the marsh 1.6 km from the edge (Brinson et al. in press a). The virtual absence of uplands at Cedar Island marsh and the highly organic sediments throughout the marsh means that there are no uplands over which to migrate. In essence, the marsh continues to build upon preexisting uplands after uplands are totally submerged. This could be considered the final stage of landscape evolution by coastal ecosystems.

Figure 14 illustrates the model being applied to many tidal marshes in coastal areas of the United States (Armentano et al. 1988, Kana et al. 1988a, b) and contrasts it with the situation as suggested for much of the nontidal wetlands influenced by Albemarle and Pamlico Sounds. In both cases there is concern over the extent to which wetlands will be able to maintain a favorable elevation with respect to rising sea level. For many of the tidal marshes, vertical accretion is supplied primarily by inorganic sediments. Unlike tidal marshes, many of the wetlands in North Carolina's sounds are relatively remote from strong alluvial sources of inorganic sediment. There is insufficient hydrologic energy to transport allochthonous materials in low energy systems (Reed 1988). Consequently, low energy environments are dependent more on autochthonous deposits of peat than on external sediment sources. Little is known about the maximum sustained rates of peat accumulation in the face of an accelerating rate of sea-level rise. In contrast, tidal marshes in North Carolina appear to be dependent on ocean-derived sands for wetland maintenance (Hackney and Cleary 1987).

When wetlands experience increasing hydroperiod, changes in species composition can be expected. In swamp forests in coastal Louisiana, apparent water level rises without compensating sedimentation are predicted to create continuously flooded conditions, thus preventing the forests from reproducing themselves (Conner et al. 1986, Conner and Day 1988). Tidal marshes in Maryland are undergoing changes in species composition and transition from vegetated to open-water habitat as the result of sea-level rise, reduced sources of sediments, and marsh management practices that rely on burning (Stevenson et al. 1985, 1986). One of the questions regarding fringe swamps is the effects of timber removal and whether the forest will be able to successfully regenerate. This will be difficult to estimate without a much clear picture of the nature of the hydroperiod in these wetlands. More hydrologic data are needed on fringe swamps to determine the relative importance of the estuaries and rainfall in water table fluctuations.



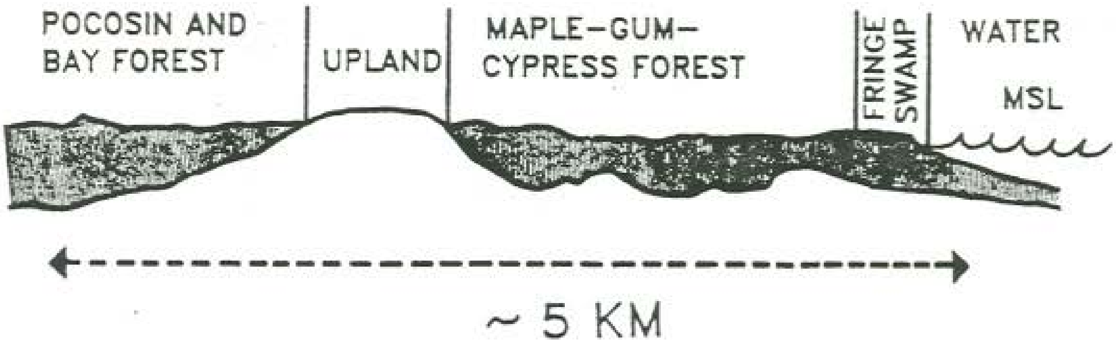


Figure 14. Top: Cross section of current zonation in a tidal marsh and zones after a net rise in sea level of 40 cm. Zones of high marsh, low marsh and tidal flat all become narrower after sea level rise because landward migration occurs up a steeper slope than the migration that brought it up to its present position. Adapted from Armentano et al. (1988) and Kana et al. (1988a).

Bottom: Conceptualized cross section of nontidal fringe swamp and interior wetlands in areas of the Pamlico and Albemarle Sounds of North Carolina. The lack of extensive uplands in close proximity to shorelines suggests that opportunities for overland migration are very limited and thus not presently an important feature of the region.

Limitations of Study

The preliminary nature of this study ensures that much information remains to be developed for fringe wetlands of the Albemarle-Pamlico region. Hundreds of kilometers of shoreline that exist along mainland portions of the sounds are both a poorly documented and poorly understood natural wetland resource in North Carolina. Waters adjacent to many of these areas have been designated as either primary or secondary nursery areas for fish and shellfish. The position of many of these wetlands at the interface between human activity and nursery areas affords protection to critical habitat that otherwise might not receive protection.

One of the valuable perspectives provided by this study is the lack of uplands in close proximity to the shoreline. Fringe wetlands are a shoreline manifestation of large expanses of swamp and marsh toward the interior. The contiguity between the fringe zone and interior wetlands means that there is no sharp boundary between the two. The transition is a continuum that is least well developed in freshwater areas that are protected from the effects of storm activity. In these areas the hydrologic signal is too weak to be expressed in strong zonation of vegetation. Forested wetlands near the edge appear to differ little from those toward the wetland interior in many cases. In brackish portions of the estuaries, both hydrodynamics and salinity exert strong control over the zonation of vegetation. The concept of fringe wetlands is quite poorly developed in the expression of vegetation because the area is largely nontidal.

There is some danger of overselling the concept of fringe wetlands in a largely nontidal area. The frequent flushing and distinct zonation that occurs in a tidal salt marsh represents the archetype of a fringe wetland. Tidal amplitudes of 2 to 3 m in some of the salt marshes of the Georgia coast provide a strong signal to which plant community zonation responds. In the nontidal regions of North Carolina's sounds, storm events transport water and sediment to fringe wetlands, shoreline erosion typifies the wetland-open water transition, and a constant supply of water provided by lateral subsurface water transport are probably the principal attributes that distinguish the fringe zone from interior wetlands. Hence, the signal to which zonation responds is much weaker and zonation of vegetation is much less distinct than in tidal fringe wetlands.

Two approaches are needed to better identify the structural and functional properties of fringe wetlands, especially in the forested regions of Albemarle Sound. First, hydrologic information is needed to identify the breadth of the zone that is influenced by water level fluctuations in the sound. This could be accomplished by installing water level recorders near the edge and toward the wetland interior similar to the arrangement on the Chowan River floodplain reported herein in Appendix D. This approach has been used in a brackish nontidal marsh on the Cedar Island National Wildlife Refuge to separate the influence of precipitation and estuarine flooding on hydroperiod along a 1.6 km transect perpendicular to the shoreline (Brinson et al. in press b). Second, more information on vegetation structure is needed to determine if the forest stands described are representative and to explore possible reasons for the large variation in species composition. Resources were not available to initiate a stratified sampling effort that would more fully illustrate the variation among sites attributed to location in the sound and variation attributable to distance from shoreline.

Finally, this study only begins to characterize the shorelines of Albemarle and Pamlico Sounds. NWI maps were not available for the northern portion of Albemarle Sound at the time of this study. From examination of preliminary drafts of that area, it appears that the fringe swamps along the several tributaries will be much different from the ones characterized for the southern part of the sound. Only a relatively small portion of Pamlico Sound was characterized in this study. In addition to the vegetation zonation and geomorphic features used to characterize fringe wetlands (Table 2), the extent to which these wetlands have been altered should be documented. Mosquito ditching, waterfowl impoundments, and dredge-and-fill activities have altered fringe wetlands, principally marshes. These activities may threaten the capacity of these wetlands to respond favorably to rising sea level.

Availability of both the natural features of fringe wetlands and the extent to which they have been altered should allow assessment of the cumulative effects of these alterations and better prepare managers with information on which to make decisions. Figure 15 is a recommendation for aggregating shoreline information into units that might be appropriate for management. The scale is one that could be used for cumulative impact analysis. Site specific information would still have to be determined from field visits because NWI maps do not provide the resolution needed for small areas. The recommendations for management and research that resulted from the workshop on "Sea Level Rise and Fringe Wetlands in North Carolina" (Appendix E) can serve as an initial guide for action that will need further refinement as progress is made.

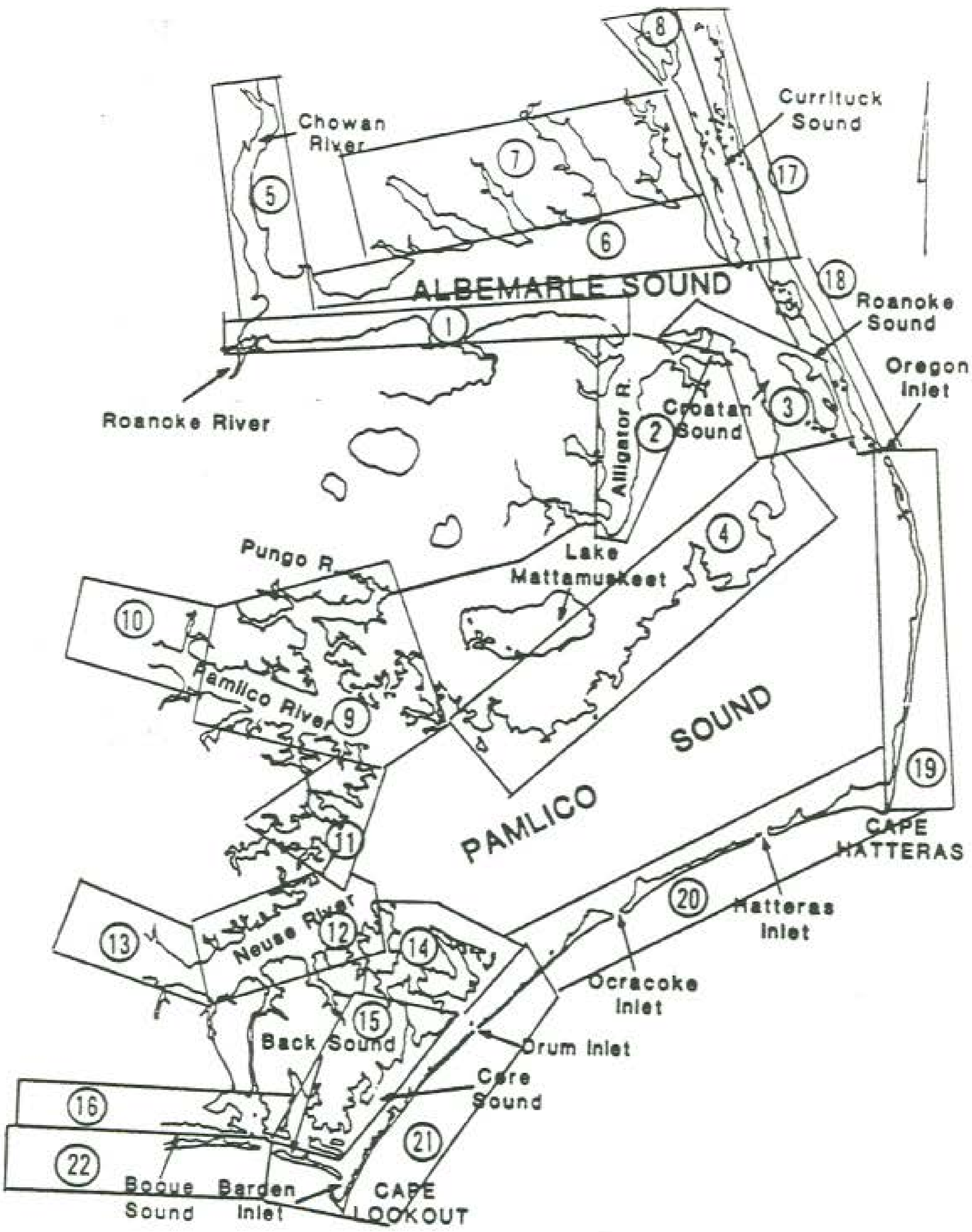


Figure 15. Proposed units of shoreline for aggregation of fringe wetland data from NWI and USGS maps. Numbering is arbitrary. Information in units 1, 2, 3, and 4 are in this report. Base map from Epperly and Ross (1986).

REFERENCES

Adams, D.A. 1963. Factors influencing vascular plant zonation in North Carolina salt marshes. Ecology 44:445-456.

Armentano, T.V., R.A. Park, and C.L. Cloonan. 1988. Impacts on coastal wetlands throughout the United States, Chapter 4, pp. 87-149. In: J.G. Titus (editor). Greenhouse Effect, Sea Level Rise and Coastal Wetlands. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C. 20460.

Bellis, V.J. and A.C. Gaither. 1985. Seasonality of aboveground and belowground biomass for six salt marsh plant species. Journal of the Elisha Mitchell Scientific Society 101:95-109

Bellis, V.J., M.P. O'Connor, and S.R. Riggs. 1975. Estuarine shoreline erosion in the Albemarle-Pamlico region of North Carolina. UNC Sea Grant Publication UNC-SG-75-29. Raleigh, North Carolina. 67 pp.

Blanck, C.E. 1980. An ecological study of bald cypress, Taxodium distichum (L.) Rich., in eastern North Carolina. M.S. Thesis, East Carolina University, Greenville, North Carolina. 179 pp.

Brinson, M.M. (editor). in press. Ecology of a nontidal brackish marsh in coastal North Carolina. U.S. Fish and Wildlife Service Open File Report.

Brinson, M. M. 1988. Strategies for assessing the cumulative effects of wetland alteration on water quality. Environmental Management 12:655-662.

Brinson, M.M., H.D. Bradshaw, and M.N. Jones. 1985. Transitions in forested wetlands along gradients of salinity andhydroperiod. Journal of the Elisha Mitchell Scientific Society101:76-94.

Brinson, M.M., W.L. Bryant, L.K. Benninger, and M.N. Jones. in press a. Composition, distribution, and dynamics of organic sediments. In M.M. Brinson (editor) Ecology of a nontidal brackish marsh in coastal North Carolina. U.S. Fish and Wildlife Service Open File Report.

Brinson, M.M., P.B. Hook, and W.L. Bryant. in press b. Hydrologic environment of Cedar Island marsh. In M.M. Brinson (editor) Ecology of a nontidal brackish marsh in coastal North Carolina. U.S. Fish and Wildlife Service Open File Report.

Browder, J.A., H.A. Bartley, and K.S. Davis. 1985. A probabilistic model of the relationship between marshland-water interface and marsh disintegration. Ecological Modelling 29:245-260.

Bruun, P. 1988. Rationalities of coastal erosion and protection: an example from Hilton Head Island, South Carolina. Journal of Coastal Research 4:129-138.

Chapman, V.J. 1976. Coastal Vegetation. 2nd edition. Pergamon Press, Oxford, England. 245 pp.

Clymo, R.S. 1984. The limits to peat bog growth. Phil. Trans. Royal Society of London B 303:605-654.

Conner, W.H. and J.W. Day, Jr. 1988. Rising water levels in coastal Louisiana: Implications for two coastal forested wetland areas in Louisiana. Journal of Coastal Research 4:589-596.

Conner, W.H., J.R. Toliver, and F.H. Sklar. 1986. Natural regeneration of baldcypress (Taxodium distichum (L.) Rich.) in a Louisiana swamp. Forest Ecology and Management 14:305-317.

Cooper, A.W. and E.D. Waits. 1973. Vegetation types in an irregularly flooded salt marsh on the North Carolina Outer Banks. Journal of the Elisha Mitchell Scientific Society 89:78-91.

Copeland, B.J., R.G. Hodson, S.R. Riggs, and J.E. Easley, Jr. 1983. The ecology of Albemarle Sound, North Carolina: an estuarine profile. U.S. Fish and Wildlife Service. Division of Biological Services, Washington, D.C. FWS/OBS-83/01. 68 pp.

Copeland, B.J., R.G. Hodson, and S.R. Riggs. 1984. The ecology of the Pamlico River, North Carolina: an estuarine profile. U.S. Fish and Wildlife Service. Division of Biological Services, Washington, D.C. FWS/OBS-82-06. 83 pp.

Currituck Sound Task Committee. 1980. Water Quality, Salinity, and Fisheries in Currituck Sound. Department of Natural Resources and Community Development, Raleigh, NC. 17 pp. (mimeo)

Daniel, C.C. 1977. Digital flow model of the Chowan River estuary, North Carolina. U.S. Geological Survey, Water Resources Investigations 77-63. Raleigh, N.C. 84 pp.

Davis, K., O. Florschutz, L. Ditto, H. Brohawn, and M. Brinson. in press. Distribution and abundance of birds on Cedar Island marsh with information on small mammals. In M.M. Brinson (editor) Ecology of a nontidal brackish marsh in coastal North Carolina. U.S. Fish and Wildlife Service Open File Report.

Day, J.W., Jr. and P.H. Templet. 1989. Consequences of sea level rise: Implications from the Mississippi Delta. Coastal Management 17:241-257.

Dolan, R., B. Hayden, and H. Lins. 1980. Barrier islands. Bioscience 68:16-25.

Epperly, S.P. and S.W. Ross. 1986. Characterization of the North Carolina Pamlico-Albemarle Estuarine Complex. NOAA Technical Memorandum NMFS-SEFC-175, National Marine Fisheries Service, Beaufort, N.C.

Fisher, J.J. 1962. Geomorphic expression of former inlets along the Outer Banks of North Carolina. M.S. thesis, University of North Carolina, Chapel Hill. 120 pp.

Godfrey, P.J. 1976. Barrier beaches of the east coast. Oceanus 19:27-40.

Giese, G.L., H.B. Wilder, and G.G. Parker, Jr. 1985. Hydrology of major estuaries and sounds of North Carolina. U.S. Geological Survey Water-supply Paper 2221, U.S. Government Printing Office, Alexandria, Virginia.

Gornitz, V., S. Lebedeff, and J. Hansen. 1982. Global sea level trend in the past century. Science 215:1611-1614.

Hackney, C.T. and W.J. Cleary. 1987. Saltmarsh loss in southeastern North Carolina lagoons: importance of sea level rise and inlet dredging. Journal of Coastal Research 3:93-97.

Hettler, W.F., Jr. 1989. Nekton use of regularly-flooded saltmarsh cordgrass habitat in North Carolina, USA. Marine Ecology Progress Series 56:111-118.

Hook, P.B. 1988. Influence of hydrology and related variables on primary productivity along an environmental gradient in an irregularly flooded brackish marsh. M.S. Thesis, East Carolina University, Greenville, N.C. 234 pp.

Kana, T.W., G.J. Baca, and M.L. Williams. 1988a. Charleston case study, Chapter 2, pp. 37-59. In: J.G. Titus (editor). Greenhouse Effect, Sea Level Rise and Coastal Wetlands. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C. 20460.

Kana, T.W., W.C. Eiser, G.J. Baca, and M.L. Williams. 1988b. New Jersey case study, Chapter 3, pp. 60-86. In: J.G. Titus (editor). Greenhouse Effect, Sea Level Rise and Coastal Wetlands. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C. 20460.

Kneib, R.T. 1984. Patterns of invertebrate distribution and abundance in the intertidal marsh: causes and questions. Estuaries 7(4A):392-412.

Knowles, D.B. 1989. Vegetation patterns and wrack-initiated disturbance in a nontidal brackish marsh in North Carolina. M.S. Thesis, East Carolina University, Greenville, N.C. 134 pp.

Komar, P.D. and D.B. Enfield. 1987. Short-term sea-level changes and coastal erosion, pp. 17-27. In D. Nummedal, O.H. Pilkey, and J.D. Howard (editors), Sea-level Fluctuation and Coastal Evolution. Society of Economic Paleontologists and Mineralogists, Special Publication No. 41. Tulsa, Oklahoma.

Kraft, J.C., M.J. Chrzastowski, D.F. Belknap, M.A. Toscano, and C.H. Fletcher, III. 1987. The transgressive barrier-lagoon coast of Delaware: Morphostratigraphy, sedimentary sequences and responses to rise in sea level, pp. 129-143. In D. Nummedal, O.H. Pilkey, and J.D. Howard (editors), Sea-level Fluctuation and Coastal Evolution. Society of Economic Paleontologists and Mineralogists, Special Publication No. 41. Tulsa, Oklahoma.

Leatherman, S.P. 1979. Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico. Academic Press, New York, N.Y.

Lugo, A.E., S. Brown, and M.M. Brinson. 1988. Forested wetlands in freshwater and salt-water environments. Limnology and Oceanography 33(4, part 2):894-909.

Marraro, P.M., G.W. Thayer, M.W. LaCroix, and D.R. Colby. in press. Distribution, abundance, and feeding of fish on a marsh on Cedar Island, North Carolina. In M.M. Brinson (editor), Ecology of a Nontidal Brackish Marsh in North Carolina. U.S. Fish and Wildlife Service Open File Report.

McIvor, C.C. and W.E. Odum. 1988. Food predation risk, and microhabitat selection in a marsh fish assemblage. Ecology 69:1341-1351.

McKee, K.L. and W.H. Patrick, Jr. 1988. The relationship of smooth cordgrass (Spartina alterniflora) to tidal datums: A review. Estuaries 11:143-151.

Odum, H.T., B.J. Copeland, and E.A. McMahan. 1974. Coastal Ecological Systems of the United States. The Conservation Foundation, Washington, D.C.

Odum, W.E. 1988. Comparative ecology of tidal freshwater and salt marshes. Annual Review of Ecology and Systematics 19:147-176.

Odum, W.E., T.J. Smith III, J.K. Hoover, and C.C. McIvor. 1984. The ecology of tidal freshwater marshes of the United States east coast: a community profile. U.S. Fish and Wildlife Service, Washington, D.C. FWS/OBS-83/17. 177 pp.

Orford, J. 1987. Coastal processes: the coastal response to sea-level variation, pp. 415-463. In: R.J.N. Devoy (editor), Sea Surface Studies, A Global View. Croom Helm, London.

Phillips, J.D. 1989a. An evaluation of the factors determining the effectiveness of water quality buffer zones. Journal of Hydrology 107:133-145.

Phillips, J.D. 1989b. Evaluation of North Carolina's estuarine shoreline area of environmental concern from a water quality perspective. Coastal Management 17:103-117.

Pickett, T.E. and R.L. Ingram. 1969. The modern sediments of Pamlico Sound, North Carolina. Southeastern Geology 11:53-83.

Pilkey, O.H. and T.W. Davis. 1987. An analysis of coastal recession models: North Carolina coast, pp. 59-68. In D. Nummedal, O.H. Pilkey, and J.D. Howard (editors), Sea-level Fluctuation and Coastal Evolution. Society of Economic Paleontologists and Mineralogists, Special Publication No. 41. Tulsa, Oklahoma.

Pomeroy, L.R. and R.G. Wiegert (editors). 1981. The Ecology of a Salt Marsh. Springer-Verlag, New York, N.Y. 271 pp.

Radford, A.E., H.E. Ahles, and C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. University of North Carolina Press, Chapel Hill. 1183 pp.

Reed, D.J. 1988. Sediment dynamics and deposition in a retreating coastal salt marsh. Estuarine, Coastal and Shelf Science 26:67-79.

Rejmánek, M. J.D. Smith, and R.A. Goyer. 1987. Population dynamics of the forest tent caterpillar (Malacosoma disstria) in a water tupelo (Nyssa aquatica) forest: a simulation model. Ecological Modelling 39:287-305.

Riggs, S.R., M.P. O'Connor, and V.J. Bellis. 1978. Shoreline erosion and accretion: a process-response classification of the shore zone environments of North Carolina. Series of five posters produced through UNC-Sea Grant project. University of North Carolina Sea Grant, N.C. State University, Raleigh.

Rozas, L.P. and C.T. Hackney. 1984. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. Estuaries 7:213-224.

Rozas, L.P. and W.E. Odum. 1987. Use of tidal freshwater marshes by fishes and macrofaunal crustaceans along a marsh stream-order gradient. Estuaries 10:36-43.

Simpson, R.L., R.E. Good, M.A. Leck, and D.F. Whigham. 1983. The ecology of freshwater tidal wetlands. Bioscience 33:255-259.

Stevenson, J.C., M.S. Kearney, and E.C. Pendleton. 1985. Sedimentation and erosion in a Chesapeake Bay brackish marsh system. Marine Geology 67:213-235.

Stevenson, J.C., L.G. Ward, and M.S. Kearney. 1986. Vertical accretion in marshes with varying rates of sea level rise, pp. 241-259. In D. Wolf (editor), Estuarine Variability. Academic Press, New York, New York.

Stirewalt, G.L. and R.L. Ingram. 1974. Aerial photographic study of shoreline erosion and deposition, Pamlico Sound, North Carolina. Sea Grant Publication UNC-SG-74-09. Raleigh, North Carolina. 66 pp.

Teal, J.M. 1986. The ecology of regularly flooded salt marshes of New England: a community profile. U.S. Fish and Wildlife Service, Washington, D.C. Biol. Rep. 85(7.4). 61 pp.

Tiner, R.W., Jr. 1985. Wetlands of New Jersey. U.S. Fish and Wildlife Service, National Wetlands Inventory, Newton Corner, Massachusetts. 117 pp.

Titus, J.G. 1988a. Sea level rise and wetland loss: an overview, Chapter 1, pp. 1-35. In: J.G. Titus (editor). Greenhouse Effect, Sea Level Rise and Coastal Wetlands. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C. 20460.

Titus, J.G. (editor). 1988b. Greenhouse effect, sea level rise, and coastal wetlands. EPA-230-05-86-013. Office of Policy, Planning and Evaluation, Environmental Protection Agency, Washington, D.C. 152 pp.

Twilley, R.R., L.R. Blanton, M.M. Brinson, and G.J. Davis. 1985. Biomass production and nutrient cycling in aquatic macrophyte communities of the Chowan River, North Carolina. Aquatic Botany 22:231-252.

USDA Soil Conservation Service. 1975. Soil erosion inventory, North Carolina. Soil Conservation Service, Raleigh, North Carolina. 29 pp.

Whyte, W.S. 1976. Basic Metric Surveying. 2nd edition. Newnes-Butterworths, London, England. 312 pp.

Wilson, K.A. 1962. North Carolina wetlands, their distribution and management. North Carolina Wildlife Resources Commission, Raleigh, North Carolina. 169 pp.

Witner, T.W. 1984. Sedimentology of the lower Chowan River, North Carolina. M.S. Thesis, Department of Geology, University of North Carolina, Chapel Hill, North Carolina. 102 pp.

Appendix A. National Wetlands Inventory maps used in determining fringe wetland types and geomorphic shoreline characteristics.

Map code	Map code
Bluff Point	Leonards Point
Buffalo City	Long's Shoal
Columbia East	Manns Harbor
Columbia West	Manteo
East Lake	Middletown Anchorage
Engelhard East	Middletown
Engelhard N.E.	Roper North
Fairfield N.E.	Stumpy Point
Fort Landing	Wanchese
Frying Pan	Westover

Appendix B. Allocation of NWI wetland types into descriptive categories.

Category	ALBEMARLE SOUTH	ALLIGATOR RIVER	PAMLICO NORTH
Brackish Marsh	E2EM1P E2SS7/EM1P	E2EM1P E2EM1P5 E2EM1P6	E2EM1P E2EM1P5 E2EM1P5h E2EM1P6 E2EM1Pd E2EM1/AB5P5
Marsh-shrub Transition		E2EM1/SS7P E2FO6/SS3B E2SS7F E2SS7/EM1F E2SS7/EM1P	E2EM1/SS3P6 E2EM1/SS7B E2EM1/SS7P E2EM1/SS7P6 E2SS1P E2SS6 E2SS6P E2SS7P E2SS7/EM1P
Bottomland Hardwoods	PFO1A PFO1/4A	PFO1/4A PFO1/4C PFO4/1C	PFO1/4G PFO4/1C
Maple-Gum-Cypress	PFO1B PFO1C PFO1Cd PFO4/1C PFO6B PFO6C PFO6/3B PFO6/4B	PFO1B PFO1C PFO1/2B PFO1/2C PFO1/7B PFO2/1C PFO6B PFO6C PFO6G PFO6/3B PFO6/4B PFO6/7B PFO6/7Bg PFO6/7c	PFO6/7B
Cypress-Water Tupelo	PFO2F PFO6F PFO6/4F PFO6/OWT	PFO1F PFO6F PFO6/4F PFO6/EM1F	

(Continued)

Appendix B. Concluded.

Category	ALBEMARLE SOUTH	ALLIGATOR RIVER	PAMLICO NORTH
Pocosin & Bay Forest	PFO1/SS3B	PEM1B	PFO4B
	PFO1/SS3F	PEM1F	PFO4/3B
	PFO3/1B	PEM1/SS4B	PFO4/6B
	PFO3/6B	PEM1/SS7B	PFO4/SS3B
	PFO4B	PFO1/4B	PFO7/EM1B
	PFO4Bg	PFO1/4Bg	PFO7/SS3B
	PFO4/1B	PFO4B	PSS3/EM1B
	PFO4/6B	PFO4C	PSS4B
	PFO/SS6F	PFO4/1A	PSS7/EM1B
		PFO4/1B	PSS7/EM1F
		PFO4/3B	
		PFO4/6B	
		PFO4/SS3B	
		PFO6/SS3B	
		PFO6/SS6B	
		PFO6/SS6F	
		PFO6/SS6T	
		PFO7/1B	
		PFO7/6B	
		PFO7/6Bg	
		PFO7/EM1B	
		PFO7/SS3B	
		PSS3/FO7B	
		PSS4B	
		PSS4C	
		PSS4F	
		PSS4/3B	
		PSS4/EM1	
		PSS4/EM1B	
		PSS6/7C	
		PSS7B	
		PSS7/EM1B	
		PSS7/EM1C	
		PSS7/EM1F	
Miscellaneous	E2BB2P	E1AB6L	E1OWL
	PEM1F	E1OWL	E1OWLx
	PFO4/1A	POWHx	E1UBL
	R1OWV	R1UBV	E1UBLx
			E2AB2L
			E2US2P
			PEM1KLG
			PUBHx
Upland	U	U	U

Appendix C. Tree and shrub species present in vegetation analysis. Nomenclature follows that of Radford et al. (1968).

Species	Common name
Acer rubrum L.	red maple
Alnus serrulata (Aiton) Willd.	tag alder
Cornus stricta Lam.	swamp dogwood
Cyrilla racemiflora L.	titi
Fraxinus sp.	ash
Ilex opaca Aiton	American holly
Ilex verticillata (L.) Gray	black alder
Liquidambar styraciflua L.	sweetgum
Magnolia virginiana L.	sweet bay
Myrica cerifera L.	wax myrtle
Nyssa aquatica L.	water tupelo
Nyssa sylvatica var. biflora (Walter) Sargent.	swamp black gum
Persea borbonia (L.) Sprengel	red bay
Pinus serotina Michaux	pond pine
Pinus taeda L.	loblolly pine
Quercus nigra L.	water oak
Rhododendron viscosum (L.) Torrey	swamp azalea
Taxodium distichum (L.) Richard	bald cypress
Vaccinium corymbosum L.	highbush blueberry

Appendix D

Interpretation of Hydrographs on Chowan River Floodplain

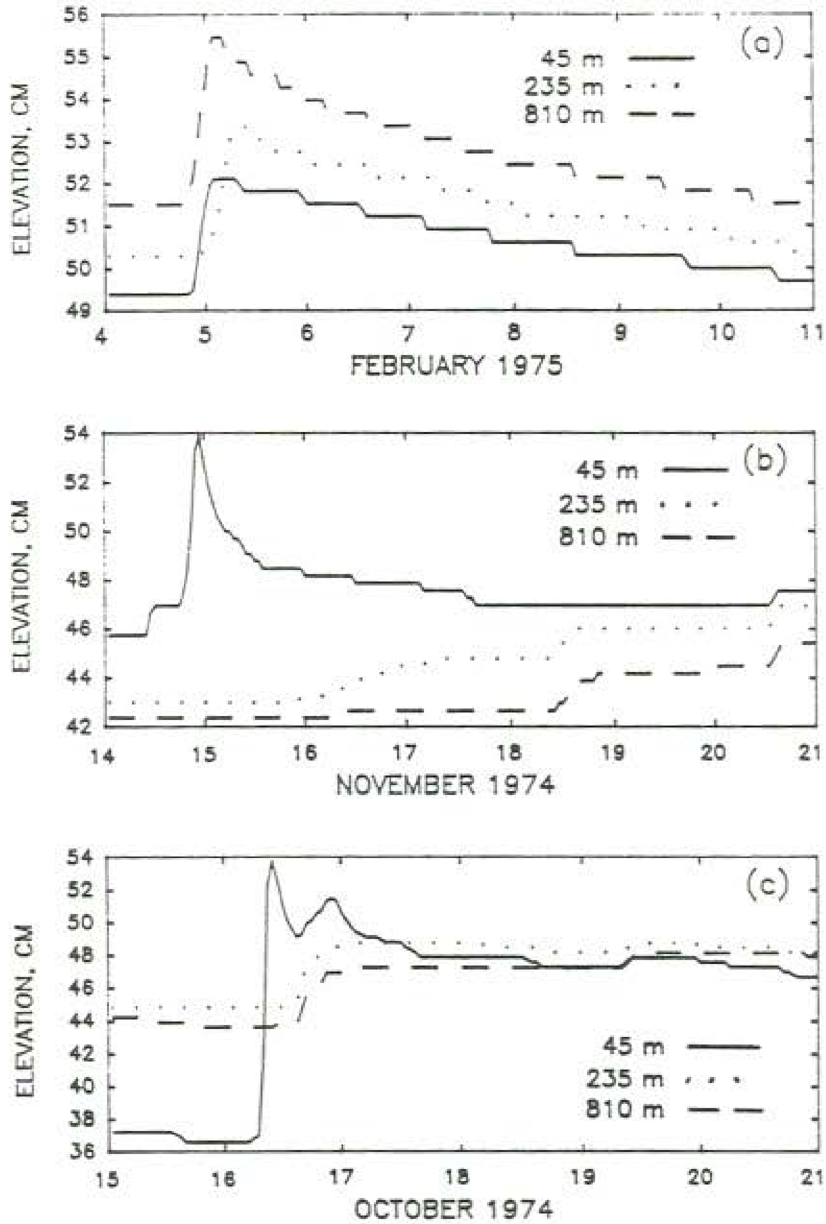
INTRODUCTION

The origin of the hydrographic data from the mid 1970s and methods for analysis are explained in the methods section. Because the analysis concluded that the floodplain was principally under the influence of riverine rather than fringe wetland hydrology, the results and discussion are presented here rather than in the body of the report.

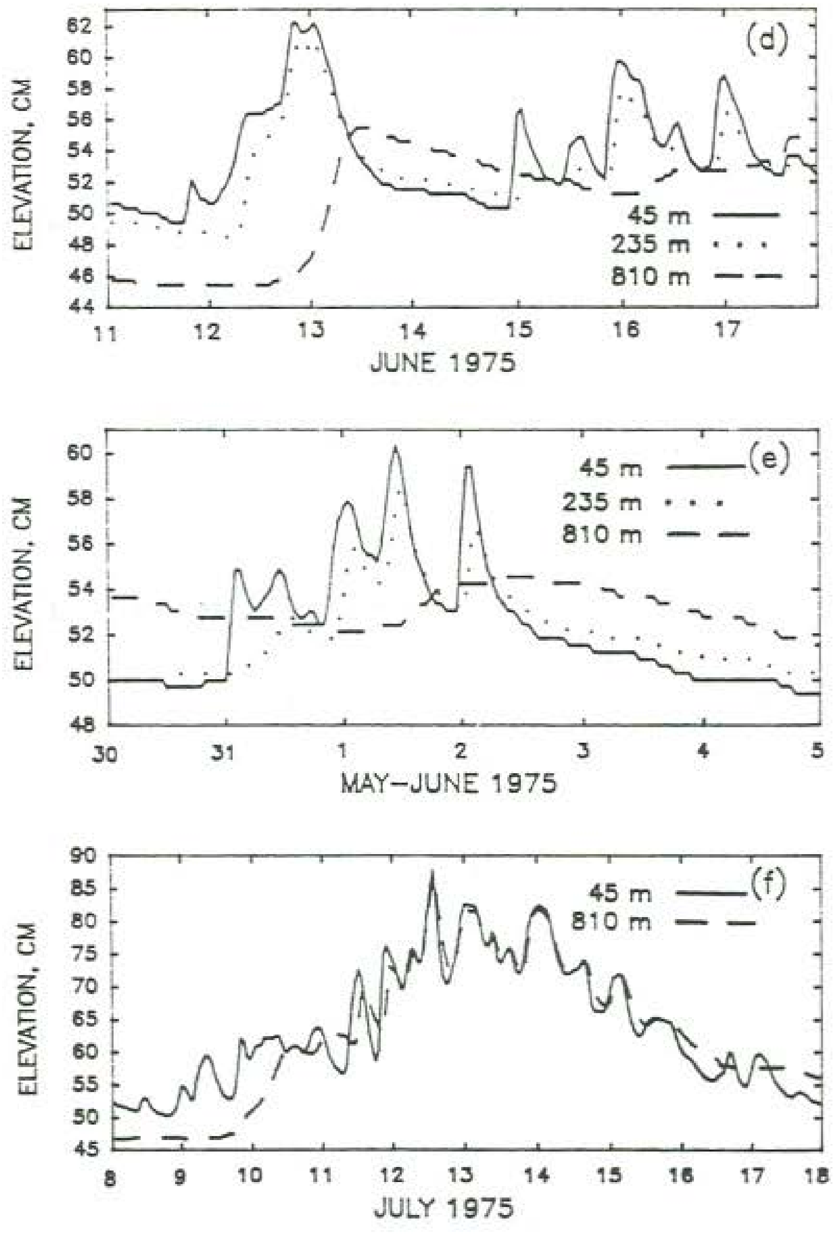
RESULTS

The source of the water table rise on 4-5 February 1975 was precipitation as indicated by the synchronous and similar magnitude of increase among stations and the fact that river stage at the time remained below the water table (Appendix Figure 1). Regional rainfall was 2.6 cm, approximately equal to the rise in water table at the 45 m site. The 235 m site rose 3 cm and the 810 m site rose 4 cm. According to the elevations of the ground surface (57 cm at 45 m and 235 m and 60 cm at 810 m), the water table remained below the surface at all three stations.

Appendix Figures 1b and 1c show events similar to each other where a sharp flood peak at the 45 m site induced flooding toward the swamp interior after time lags ranging between several hours and one day. For example, the event of 14-20 November had a lag of over 1 day between the rise in water table at 45 m and the rise at the other two sites. The position of the water table below the surface at all sites suggests considerable amount of subsurface lateral transport can occur. It is curious that the 45 m stage recorder did not respond to what is presumed to be precipitation, i.e., synchronous increases at the 235 m and 810 m sites on 18 November, but did on 20 November. The 15-20 October period shows a mixed event of riverine flooding and precipitation (Appendix Figure 1c). After flooding from the river at the 45 m site, there were corresponding increases after several hours lag at the other two sites where water levels converged. However, rainfall received on 16 October caused a secondary peak at 45 m and steep rises at the other two sites. Even if the rainfall had not obscured water table fluctuations due to the initial flood peak, there was probably insufficient hydrostatic head across the swamp to cause lateral transport and drive subsurface flow to the interior sites as in the previous example (Appendix Figure 1b).



Appendix Figure 1. Hydrographs of flood events at Rayes Beach on the Chowan River. Water table elevations are for three stations located at increasing distances into the swamp from the shoreline. Legend at bottom of graphs gives distances from shoreline (m). Elevation of the forest floor is 57 cm at the 45 m and 235 m sites, and 60 cm at the 810 m site. The digital nature of the data at a resolution of 0.01 foot (0.3 cm) is the reason for the stairstep form of the curves. Note that scales differ among graphs.



Appendix Figure 1. Concluded.

The period 11-17 June 1975 had river-induced flooding with lags between 45 m and 235 m as well as between 235 and 810 m (Appendix Figure 1d). Approximately 0.9 cm rainfall was received on June 12 which is likely reflected in one of the double peaks at 45 m and 235 m as well as the small shoulder at the bottom of the rising limb at 810 m. No precipitation occurred during 15-17 June. The water level fluctuations at 45 m and 810 m were due entirely to river stage. The lack of synchronized fluctuations at the interior site indicates weak coupling with the river when stages were below 60 cm. Loose coupling is implied, however, because of water level rises at 810 m on 16 and 17 June.

The hydrograph for 30 May-4 June 1975 apparently was responding to overbank flooding from the river (Appendix Figure 1e). About 2.5 cm precipitation in the area before this period (28 May) likely initiated this flood. The water level fluctuations in the swamp were a result of changes in river stage as confirmed from stage records. High river stage and abundant local rainfall during 8-17 July (Appendix Figure 1f) of the same period potentially confound separation of river induced flooding and precipitation events. (Records for the intermediate station are missing for this period.) However, the synchrony between the two stations 765 m apart illustrates that they had strong hydrologic connections when stages were approximately 65 cm or higher. The periodicity of the oscillations superimposed on the broad, week-long hydrograph suggests that they could be a result of semidiurnal tides. Wind-induced water level fluctuations and diurnal changes in runoff as a result of evapotranspiration could amplify or obscure the tidal signal depending on periodicity. The presumed tidal influence of up to 10 cm obscures these potential sources of influence.

In summary, several types of flood events can occur. First, rainfall alone can raise water tables to or above the surface with subsequent drainage or loss by evapotranspiration. Second, flooding from the river channel may also raise water tables to flood stage; the lag time between flooding near the channel and flooding of the swamp interior at 810 m from the channel ranges between a few hours to 1 day. When the water table is initially low, the hydraulic coupling among sites is weak and lag times are prolonged. When deep flooding occurs, regardless of source, water table fluctuations are closely coupled with the river, and fluctuations are synchronous with those in the river. Combinations of these types of events are common. No unambiguous wind-initiated events were elucidated, suggesting that the site is controlled by riverine hydrology.

DISCUSSION

The swamp at Rayes Beach on the Chowan River has riverine characteristics based on both hydrology and sediments. Therefore, it is not representative of fringe wetlands nearer the Albemarle Sound. Sources of flooding and water level fluctuations appeared to be associated with runoff induced by precipitation in the basin rather than with flooding induced by wind or astronomic tides. The influence of wind tides this far up the on the Chowan River cannot be ruled out, however, and may have been obliterated by river induced flooding. A probable lunar tide signal far into the swamp during high stage of the river (Appendix Figure 1f) indicates, however, that wind induced fluctuations could also influence the swamp interior. For the period of observation, it appears that headwater flooding is necessary to cause the interior of the swamp to respond to water fluctuations at the edge. Although Daniel (1977) suggested that the seasonal pattern of water levels in the lower Chowan was due to southerly winds causing higher levels in the summer and northerly winds causing lower levels in the winter, it is more likely that an adjustment is being made to the seasonality of sea level. Pattullo et al. (1955) have demonstrated that temperature-induced steric effects in the ocean are responsible for a strong seasonal component to sea level in our region. This has been confirmed for Pamlico Sound where seasonality of sea level, wind field, and evapotranspiration combine to control hydroperiod in brackish marshes (Brinson et al. in press).

Wetlands bordering Albemarle Sound would be expected to receive flooding from wind tides independent of runoff from drainage basins. We would expect the headwater flooding signal to be weak and the wind tide influence to be stronger. Consequently, periodicity of flooding would correspond to wind direction and force in relationship to the position in the Albemarle Sound. The riverine nature of the Rayes Beach site may mean that the modal stage of the river is lower in relationship to its riverine floodplain than the stage of Albemarle Sound in relation to its fringe wetlands. If this is the case, then less magnitude in fluctuation would be required for an equivalent hydrologic influence on the adjacent wetland of Albemarle Sound.

Superficially, the nature of the vegetation and the topography of the forest floor for the Rayes Beach site do not appear to differ greatly from the sites examined on the Alligator River. Chowan River surface sediments were more often clayey peats rather than the peaty clays found at the Poplar Point site. The greater clay content at the Chowan River site is likely the result of alluvial deposition (Witner 1984). The different sediment textures among sites and could have an important influence on lateral transport of water and vertical fluctuations from precipitation. Consequently, extrapolation from Rayes Beach to sites located nearer Albemarle Sound is not recommended. Hydrologic studies on these fringe swamps remains to be done.

REFERENCES

Brinson, M.M., W.L. Bryant, L.K. Benninger, and M.N. Jones. in press. Composition, distribution, and dynamics of organic sediments. In M.M. Brinson (editor) Ecology of a nontidal brackish marsh in coastal North Carolina. U.S. Fish and Wildlife Service Open File Report.

Daniel, C.C. 1977. Digital flow model of the Chowan River estuary, North Carolina. U.S. Geological Survey, Water Resources Investigations 77-63. Raleigh, N.C. 84 pp.

Pattullo, J., W. Munk, R. Revelle, and E. Strong. 1955. The seasonal oscillation in sea level. Journal of Marine Research 14:88-155.

Witner, T.W. 1984. Sedimentology of the lower Chowan River, North Carolina. M.S. thesis, Department of Geology, University of North Carolina, Chapel Hill, North Carolina. 102 pp.

Appendix E

SEA LEVEL RISE AND FRINGE WETLANDS IN NORTH CAROLINA:

RECOMMENDATIONS FROM A WORKSHOP ON MANAGEMENT AND RESEARCH

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ABSTRACT: Estuarine shorelines in North Carolina are extensive. The wetlands that occupy much of these shorelines are a resource worthy of sound management and protection. Acceleration in the rate of sea level rise caused by global warming will alter the location and perhaps the quality of fringe wetlands in the state. A workshop held on 1 March 1989 brought together professionals to make recommendations for management and research to deal with fringe wetlands and sea level rise.

Management recommendations fell into two categories: those that are possible with current management frameworks and those that will require changes in existing regulations. The first category can be implemented largely by creating an environment of greater awareness among resource managers about the short and long term implications of sea level rise for coastal wetlands and adjacent regions. The second category will require removal of incentives for wetland alteration and creation of disincentives for activities that interfere with shoreline processes important to wetland maintenance.

Research is needed to reduce the many uncertainties that exist on rates and timing of sea level rise, site-specific changes in shoreline position and erosion rates, and the influence of larger scale phenomena such as climatic patterns and oceanic circulation on wetland ecosystems. The attempt to predict future conditions is impeded by a lack of understanding of ecological and geological processes in coastal wetlands. Rates of accretion of wetland surfaces; effects of alterations such as ditches, impoundments, and altered hydrology; and the ecological role of wetlands on a landscape scale are but a few of the issues that need to be addressed.

INTRODUCTION

Accelerated emissions of the so-called greenhouse gases to the atmosphere have unwittingly initiated one of the most daring global experiments in human history. While the debate continues among scientists about the strength of connection between sea level rise and the greenhouse effect (Peltier and Tushingham, 1989), few doubt that global warming will ensue and the rate of sea level rise will accelerate (Devoy, 1987). If we assume that each geographic region of earth will encounter a slightly different suite of climatic changes, successful adaptations of society to these changes will require solutions that make allowance for the peculiarities of local culture and geography. In this regard, coastal North Carolina can be conceptualized as a sparsely populated region being subjected to a retreat in shoreline position as a result of sea level rise. Such a characterization ignores the fact that not all coastal areas are sparsely populated nor are the shorelines homogeneous in their response to sea level rise. Further, accelerated rates of land development for housing and recreation on the coast intensifies the conflicts between shoreline dynamics and human activities. The status of planning for these conflicts is quite primitive. We are clearly intensifies the conflicts between shoreline dynamics and human activities. The status of planning for these conflicts is quite primitive. We are clearly in the early stage of the learning curve for dealing with the complexity of issues that accelerated sea level rise will create.

The importance of fisheries and the role that wetlands appear to play in providing support for these fisheries raises the issue of the response of wetlands to accelerated rates of sea level rise. In North Carolina many of the fringe wetlands of the Albemarle and Pamlico Sounds are under the control of sea level rise, yet they lack the strong astronomic tides that are responsible for sediment transport in other coastal wetlands. Consequently, information gained from other geographic regions may not be strictly applicable to North Carolina, a situation which warrants a close examination of the mechanisms that allow wetlands to respond to sea level rise. There are many poorly understood dimensions and facets on the effect of sea level rise on wetlands. Although additional work and planning remains to be done before a definitive strategy is developed for our state, several common-sense recommendations may be implemented at once. The purpose of the workshop was to develop ideas for coping with the problem as it relates to the extensive wetland ecosystems that represent much of the important interface between our estuaries and the land.

Panels consisting of researchers and managers from North Carolina met on March 1, 1989 at East Carolina University to offer their recommendations on the response of fringe wetlands in the state to sea level rise. Emphasis was placed on the sea level controlled, but largely nontidal wetlands of the Albemarle and Pamlico Sounds. This report is a summary of their recommendations for management and research.

Several speakers provided background information before the panel discussion. Mr. Paul Wilms, Director of the Division of Environmental Management (NRCD), provided North Carolina's perspective on wetlands and sea level rise by discussing the regulatory and political climate of wetland and water quality protection. Dr. Mark Brinson, East Carolina University, defined fringe wetlands, briefly outlined past research on these ecosystems, and questioned the utility of some models that predict the response of wetlands to sea level rise for North Carolina's nontidal wetlands. Dr. John W. Day, Louisiana State University, described the rapid apparent sea level rise in the Mississippi Delta, the massive losses of wetlands in the region, and the land uses in the region that exacerbate wetland losses (Conner and Day, 1988). Dr. J. Court Stevenson, University of Maryland, emphasized the dependence on sediment supplies of tidal wetlands in the Chesapeake Bay region and illustrated how wetlands deteriorate when sediment sources are lacking (Stevenson et al., 1986).

The recommendations represent a giant step in drawing together the expertise of researchers and managers that have given much thought to the influence of sea level rise on coastal wetland resources. The list should be further scrutinized with the goal of not only adding, refining, and prioritizing recommendations, but also of implementing programs of action, especially within the context of new and emerging policies such as no net loss of wetlands (The Conservation Foundation, 1988). The task of developing needed information and implementing management strategies is urgent because lag times may be on the order of decades before the response of the natural system to rising sea level becomes evident. Action is needed to protect wetlands that are important to our natural heritage. The exact direction of this action will likely undergo several phases of self-correction. Although thoughtful planning at this early stage will incur some cost to society, the costs are likely trivial compared to future costs that would be forced upon governments and individuals without planning (Titus 1987). Regardless of the uncertainty in direction and priorities at this time, two issues are certain. First, wetlands are vital to the life support of humans, plants, and animals of the coastal region and, second, future landscape positions of fringe wetlands will change as sea level rises.

MANAGEMENT RECOMMENDATIONS

Management recommendations fall into three major categories:

1. Those that can be applied without changes in existing regulations and laws. While some recommendations may conflict with the policy of some agencies with responsibilities over wetland and shoreline resources, it is also true that these same agencies may not have the advantage of current information on the changing conditions of sea-level controlled, fringe wetlands.

2. Those that may require changes beyond the administrative or policy level. These may require additional documentation in order to justify regulatory or legislative action. Documentation may be developed in the form of surveys or research.

3. Those that require additional information before management choices can be made wisely. Some of this information could fall under the category of research recommendations. They are placed under the management section either because they represent fundamental impediments to management progress or they represent potentially productive areas in which researchers and managers could interact.

Action Possible within Current Management Framework

1. Cost-benefit analyses and other evaluations of coastal resource allocation are currently used to determine whether management decisions are in the best interest of society. The relationship between sea level rise and future wetland resources should become a routine and obligatory part of these review processes.

2. Conservative estimates of sea level rise can be used with confidence and factored into short term planning needs on the order of 4 to 25 years. This time scale covers the approximate range between political cycles (elections) and economic speculation (mortgages).

3. There is a need for administrative flexibility that recognizes the changing dynamics of the landscape for regulatory and management purposes. Explicit recognition of the influence of sea level rise on wetlands should be made at all levels of decision making and enforcement of regulations.

4. Maps of "flood-prone areas" should be updated periodically, perhaps once every 5 to 10 years, to reflect revised sea level stands and shoreline positions. The relationship of flood-prone areas and the potential effects of oil spills should be assessed.

5. Strict approaches need to be implemented to stopping construction in low-lying areas, unless buildings are designed to resist flood damage.

6. Plans for relocation of human resources affected by wetland migration and changes in hydrology need to be developed. Although there is much debate on the future rate of sea level rise, the direction is seldom questioned. Hence, it is possible and desirable to develop plans for shifts in relocation separate from timing. The exact timing for relocation, therefore, can be deferred until more precise estimates become available on rates.

7. More creativity and imagination are needed in management for increased waterfowl and wildlife abundance rather than relying on decades-old techniques that were developed without consideration for sea level rise. New and modified techniques should be examined so they do not interfere with the capacity of wetlands to maintain their integrity when subjected to sea level rise. For example, waterfowl impoundments built in sea-level controlled marshes impede natural hydrologic exchanges between estuaries and wetlands. As such, marsh impoundments are probably incapable of responding to rising sea level in the same way that natural marshes undergo accretion at the surface either through accumulation of allochthonous sediments or by accumulation of organic matter. Alternatives may exist, such as opportunities for moist soils management for wintering waterfowl on agricultural or silvicultural land (Auble et al., 1988) that was abandoned due to increased flooding frequency and brackish water intrusion.

8. Creativity and effort are also needed in managing fisheries. We need to develop ways of sustaining good harvests of shrimp, oyster, crabs, and anadromous fish. The extent to which management alternatives are influenced by sea level rise and associated changes in wetlands has not been assessed.

9. There is a greater urgency to plan for sea level rise for silviculture than for agriculture because of longer rotation times of the forests. Forest management will have to intensify some practices and reduce the intensity of others. Forms of more intensive management may include water control (pumping and tide gates), increasing bedding height, genetic manipulation, decreased rotation lengths, alternative harvest techniques, and use of agroforestry. Forms of decreased management intensity may include natural regeneration and aerial seeding, harvest techniques to maintain transpiration rates (partial harvest or small clearcuts), and selecting species tolerant to wetter conditions.

Changes Required in Existing Regulations

1. Risks of landward encroachment of wetlands and estuarine shorelines should be borne by individuals, not by society. This may require implementing disincentives for activities that interfere with wetland response to sea level rise as well as further removal of incentives for wetland alteration (e.g., Food Security Act).

2. Management practices within or adjacent to wetlands should not interfere with the capacity of wetlands to respond to sea level rise. Unaltered wetlands should receive the highest protection level. Degraded wetlands should be restored to enhance their capacity to respond to sea level rise. Marshes that were once ditched may be favorable targets for enhancement. Little information is available on how restoration can be carried out effectively.

3. The jurisdiction of the state's inland and marine fisheries should be coordinated in such a way that best serves the total resource. Designated nursery areas and monitoring efforts need to respond to changes associated with sea level rise.

Information Needs for Managers

1. Accurate information on the rate of sea level rise is necessary for developing appropriate regulations that apply to wetlands. Good communication with those affected should be established once the risks become known.

2. Site specific information is needed on wetland response to sea level rise in sufficient detail to influence the decision-making of individual land owners, county and city planners, and regulators. Examples include rates of erosion, areas amenable to wetland migration versus other potential uses, and better information on elevations. Such information is dependent on developing topographic maps at finer scales of resolution, having a better understanding of the causes of shoreline recession rates, and being able to predict how fringe wetlands will encroach upon uplands and interior wetlands.

3. With little increase in cost, minor alteration of existing monitoring and research programs may yield information that will improve our understanding of the environmental and biological changes associated with sea level rise and wetland processes. Researchers and managers should explore together possible opportunities in this regard.

RESEARCH RECOMMENDATIONS

Most research recommendations fall into two categories: (1) the need for better models that recognize the largely nontidal and partially forested nature of North Carolina's fringe wetlands and (2) the need to better understand how these ecosystems function ecologically and respond to perturbations.

Models and Predictions

1. Predictive models on the influence of sea level rise on wetlands are needed at several temporal and spatial scales of resolution. It is important to identify the boundary conditions of time and space for which predictions are being made and hypotheses are being tested. It should be recognized also that there is usually a trade-off between the size of scale and the resolution or accuracy of predictions.

2. The models developed for tidal wetlands are probably inappropriate for many of the wetlands on the mainland of North Carolina in the Albemarle and Pamlico Sounds. For example, one EPA model developed for calculating rates of overland migration and zonation changes within marshes relies, in part, on the presence of two elevational gradients: one within tidal marshes and the other on elevational gradients in adjacent uplands (Titus, 1988). Nontidal or weakly tidal wetlands in the sounds either do not possess these slopes or an upland is not present for overland migration to occur. Another approach is the use of contour intervals on topographic maps to forecast shorelines with a given rise in sea level. This approach ignores the past and present role that wetlands have played in landscape development and maintenance. It also ignores current land ownership and responses to sea level rise by human society. Alternate approaches need to be developed for predicting the influence of sea level rise on wetlands.

3. Models are needed to predict where erosion will take place and at what rate. Site specific information is needed on fringe wetland shoreline erosion, the boundary between fringe wetland and either upland or interior wetlands, and where migration will take place. These processes need to be integrated to determine whether wetland gain or loss will occur.

4. There is a need for better predictions of the large-scale changes that may take place with sea level rise. Loss of barrier islands, closing or opening of inlets, changes in oceanic circulation patterns, and alteration of wind fields may make research recommendations designed for present conditions obsolete.

5. There are many other questions regarding fringe wetlands for which we have no answers. It is even difficult to determine which questions are most urgent and which are of marginal utility.

> How will pCO_2 and higher temperatures affect survival, productivity and community succession? Will site water balance change to make the wetland better drained or more flooded?
>
> What is the maximum rate of sea level rise endurable by existing marsh and swamp ecosystems? If wetlands are lost, with what will they be replaced?
>
> Will the relationship between import/export processes and organic matter accretion change in wetlands?

What will be the impacts on quality of the water periodically flooding these wetlands? Can we expect changes in nutrient cycling, phytoplankton productivity, fisheries harvests, waterfowl production, and coastal recreation?

Understanding Present Conditions

1. A regional survey of accretion rates is needed to determine which wetlands are actively accreting and which are not. The survey should be designed to reveal why some are able to maintain a favorable elevation with respect to sea level rise while others fail to do so. One of the goals would be to sort out the extrinsic and intrinsic controls on wetland accretion. This information could have strong management implications for providing additional protection status to some wetlands and conducting restoration activities in others.

2. We need to know the relative importance of the two principal sources of material for the vertical accretion of the wetland surface. These sources are (1) estuarine sediments that are resuspended and transported to the marsh surface during storm-induced flooding and (2) organic matter that has accumulated from in situ primary production. Organic matter accumulation not only contributes locally by allowing the surface elevation to increase with rising sea level, but also serves a global role as a carbon sink for carbon dioxide.

3. Much needs to be learned about the response of wetlands to man-induced and natural disturbance. For marshes, common sources of disturbance are ditching, diking, and frequent burning. For forested wetlands, timber harvest and drainage are common types of disturbance. In each of these cases, recovery from disturbance can be roughly predicted with current rates of sea level rise. However, data are lacking especially for forested wetlands of the region. The challenge is to gain insight into potential trajectories of plant community succession on one hand and the potential for vertical accretion of sediments on the other under accelerated rates of sea level rise.

4. Many kilometers of ditches have been dug in coastal marshes for mosquito control, a practice that is highly restricted at this time. The capacity of these and other altered wetlands to be self-sustaining needs to be assessed. It may be possible to take corrective action to rehabilitate these and other altered wetlands.

5. There is need for interdisciplinary research in wetlands such that geologists, ecologists, hydrologists, and fisheries and wildlife biologists cooperate in trying to understand wetland dynamics.

6. Progress needs to be made on understanding the following questions and issues. What will limit the landward migration of coastal wetlands as sea level rises, geographic features or human intervention? What is the relative importance of sea level rise to shoreline erosion rates? Will total area of wetlands increase or decrease? Ownership patterns should be analyzed with respect to the site-specific impacts of sea level rise and change in position of wetlands.

7. Little information is available on wetland hydrology, especially for fringe wetlands. Because hydrology has such a profound influence on wetland structure and function, changes in land use practices could have an influence on the hydrology of adjacent wetlands (i.e., recharge-discharge relationships). Information is needed on the degree of coupling between hydrologic controls and wetland functions. There is a whole set of questions related to the response of wetland ecosystems to global warming and climatic changes independent of sea level rise. Site water balance in wetlands may change with changes in precipitation and evapotranspiration.

8. An evaluation is needed on the transfer of management practices from tidal marshes to nontidal brackish marshes. Open marsh water management for mosquito control and impoundments for waterfowl habitat improvement represent two common examples.

9. There is a need for understanding the role of global warming, independent of sea level rise, on primary productivity, geographic redistribution of species (i.e., northward migration of mangroves), and rainfall distribution. Insight can be gained on these processes through a better understanding of individual species' responses to altered climatic, edaphic, and hydrologic conditions.

10. A better understanding of the ecological functions of fringe wetlands, both marsh and swamp, is needed. Few baseline data on primary productivity and nutrient removal, for example, are available for comparison with future conditions of higher sea level. Are fringe wetlands important in the exchange of nutrients and detritus with estuaries? Contrariwise, as estuaries themselves change, how will they affect the gradients, structure, and function within fringe wetlands? Sea level rise may be expected to result in changes in nutrient status, circulation patterns, stratification, wind fields, and salinity of estuaries. More information is needed on the relative tolerance of plant species to changes in hydroperiod and salinity. Significant nutrient and detritus exchanges between wetlands and the estuary have direct influences on water quality (phytoplankton productivity, bottom-water hypoxia, etc.) and on potential fisheries harvests.

11. Although most recommendations have addressed needs for nontidal fringe wetlands, many apply to tidal marshes. Tidal wetlands are a very important natural resource in North Carolina. Extensive tidal salt marshes are found in Pamlico Sound near ocean inlets and in backbarrier locations along the remainder of the state's shoreline to the south. Predictive models and other information being developed in North Carolina (Hackney and Cleary, 1987) and elsewhere should be applicable for these tidal wetlands. It is especially important to determine the relationship between the supply of marine sands and the integrity of back barrier tidal wetlands.

CONCLUSIONS

This report summarizes recommendations for management and research on coastal fringe wetlands that are under the influence of sea level rise. Although considerable research is needed to comprehend the effects of sea level rise on wetland resources, management issues regarding government and landowner responsibilities to our coastal resources should receive immediate attention before problems intensify. Considerable savings in both wetland and economic resources can be realized by early planning. The recommendations listed in this report can serve as an initial effort toward strategic planning for both management and research opportunities in North Carolina. The diversity of expertise among panel members and the resulting recommendations suggest that cooperation between managers and researchers is essential for a comprehensive treatment of the topic. Such cooperation should be thoroughly utilized to resolve landscape-level problems such as sea level rise.

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