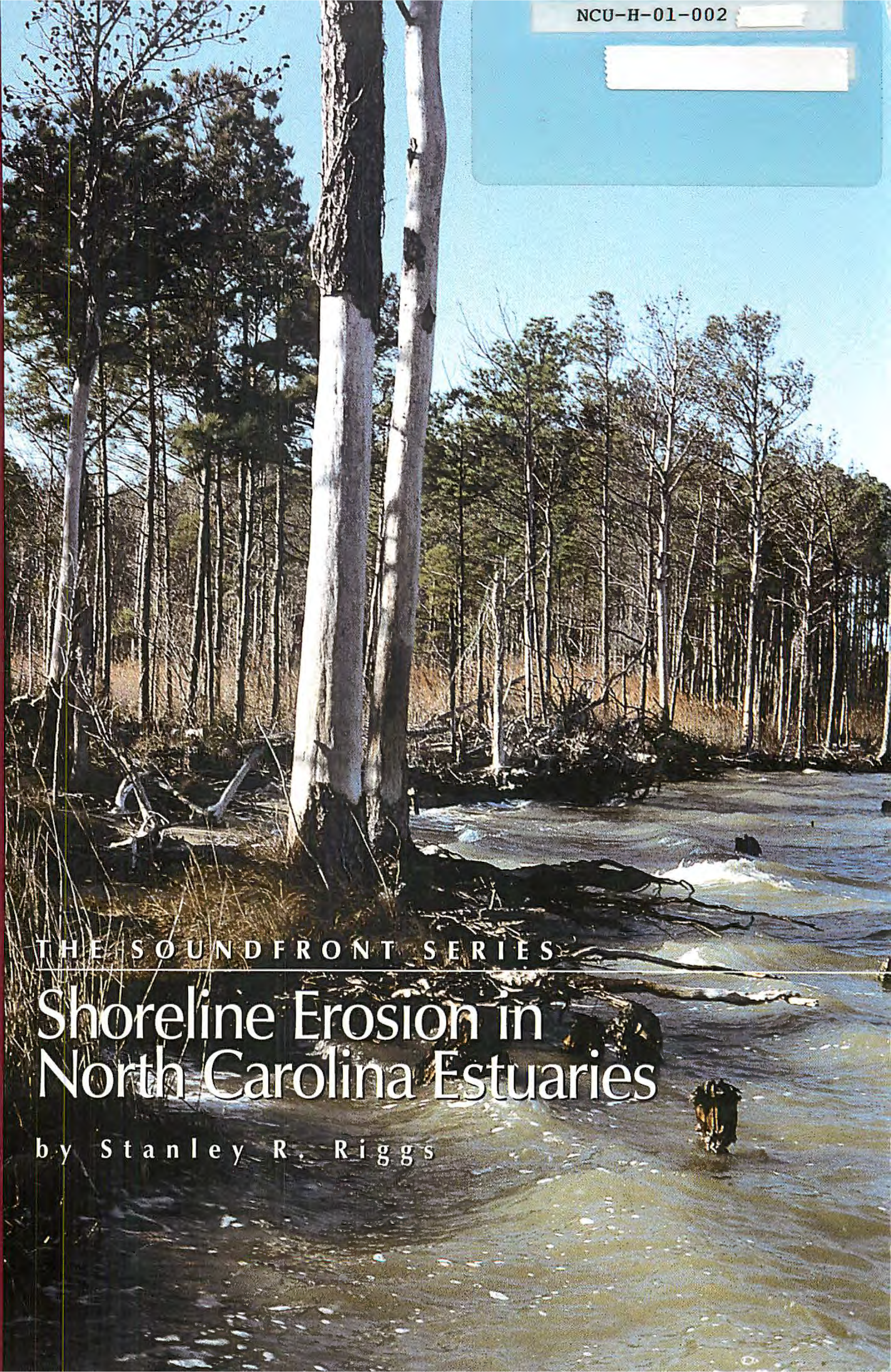

THE SOUNDFRONT SERIES

Shoreline Erosion in North Carolina Estuaries

by Stanley R. Riggs

The Soundfront Series

PREFACE

The estuarine areas of North Carolina are seeing increased residential and commercial development, with more proposals on the horizon. Sustainable use of these areas requires awareness, understanding and implementation of sound design and management options. The long-term environmental health of the land, water and natural resources will benefit the growing economy and quality of life.

The N.C. Division of Coastal Management with North Carolina Sea Grant and the North Carolina State University College of Design developed *The Soundfront Series*, informational guides to assist property owners and community planners and managers. The guides are available in print and on the Web.

The series includes:

- *Shoreline Erosion in North Carolina Estuaries*, by Stanley R. Riggs. UNC-SG-01-11. Riggs is a distinguished professor of geology at East Carolina University.

- *Managing Erosion on Estuarine Shorelines*, by Spencer Rogers and Tracy E. Skrabal. UNC-SG-01-12. Rogers is North Carolina Sea Grant's coastal erosion and construction specialist. Skrabal is a senior scientist with the North Carolina Coastal Federation.

- *Protecting Estuarine Water Quality Through Design*, by Nancy White. UNC-SG-01-13. White is a research associate professor of landscape architecture in the College of Design at North Carolina State University.

- *Protecting the Estuarine Region Through Policy and Management*, by Walter Clark. UNC-SG-01-14. Clark is North Carolina Sea Grant's coastal law and policy specialist.

Lundie Spence, marine education specialist for North Carolina Sea Grant, and Bill Crowell and Michael J. Lopazanski of the Division of Coastal Management, served as coordinators and technical editors for the series. Katie Mosher, Ann Green and Pam Smith, all of the North Carolina Sea Grant communications team, edited the series.

For information on the Division of Coastal Management, call 919/733-2293 or 888-4RCOAST. The division's Web site includes information on permits and regulations, as well as contacts for regional offices. Go to *www.nccoastalmanagement.net*.

For information on North Carolina Sea Grant — and to order individual guides or the complete series — call 919/515-2454. Online, go to *www.ncsu.edu/seagrant*.

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Shoreline Erosion in North Carolina Estuaries

Chapter 1: The Estuarine Shoreline Erosion Dilemma

North Carolina's estuaries represent a geologically young and dynamic portion of the coastal system. Estuarine coastal systems occur where ocean waters mix with river waters. As the last great Pleistocene ice sheet began to melt in response to global climate warming over 10,000 years ago, the present coastline began to develop.

As the glaciers melted and receded, the meltwaters raised the ocean level. This rising sea level caused the coastal system to migrate across the continental shelf, flooding over the land and up the topographically low-river valleys to form our present estuarine system.

After 10,000 years, 425 feet of sea-level rise, and a lateral migration of 15 to 60 miles westward, the North Carolina coast began to develop its now familiar look of estuaries and barrier islands.

The world's glaciers are still melting today. Sea level continues to rise. And the ocean, slowly but relentlessly, floods the coastal lands of North Carolina. This results in the ongoing upward and landward migration of the shoreline — a process better known as shoreline erosion. People who build near the estuarine shoreline become partners in this natural process.

The fact that sea level is rising worldwide means that erosion is ubiquitous to all of North Carolina's thousands of miles of shoreline. The only differences are the rates of erosion, which are dependent upon specific shoreline variables and varying storm conditions. Locally, a shoreline may appear stable or actually accrete sediments, but such a situation is usually ephemeral.

Change is a constant within dynamic coastal zones and guarantees no permanency to any structure or feature along the shorelines. For those who live and work along the water's edge, an extremely high level of property loss results from storm-induced flooding and shoreline erosion. The burgeoning population and exploding development demand for shoreline stabilization to protect property. However, such efforts can result in negative impacts upon the coast and a cumulative toll on the health of the entire estuarine system.

Native Americans inhabited coastal North Carolina prior to 10,000 years ago. However, there are few records remaining of their occupancy. Even the record of the first European settlement on Roanoke Island in 1585 has been obliterated by shoreline recession. Consequently, great monuments from our present coastal civilization will probably not survive into antiquity. Today, the processes of change continue to take their toll as every nor'easter and hurricane place their mark upon the shifting sands of time. This is our coastal heritage.

Facing page: This high sediment bank is actively eroding.

In 1975 Vince Bellis and colleagues used the demise of Batt's Island in Albemarle Sound to demonstrate the process of estuarine shoreline recession in response to rising sea level. This island, which occurred about 0.75 miles offshore of Drummond Point at the entrance to Yeopim River, first appeared on the 1657 Comberford map (Cumming, 1938) as Hariots Island. The island subsequently became the home of Captain Nathaniel Batts, the first Virginian to settle in the Albemarle region and the governor of "Roan-oak." The island is referred to as Batts Grave on the 1733 Moseley and 1770 Collet maps (Cumming, 1966) (Figures 1.1A and 1.1C). In 1749 the island consisted of 40 acres occupied by houses and orchards (Powell, 1968). Bellis et al. (1975) estimated that the island was about 10 acres in size on an 1849 U.S. Coast and Geodetic Survey map. By the early 1970s, a lone cypress skeleton marked the total demise of the island (Figure 1.1B) and by the early 1990s a red buoy marker reflected the presence of shallow shoals (Figure 1.1D).

The loss of Batt's Island is symbolic of the ongoing loss of land in eastern North Carolina (Table 1.1). Over 500 acres are lost per year, and over 40 square miles of land has been lost between 1975 and 2000.

This guide provides key concepts in understanding the various types and rates of estuarine shoreline change from a geologist's perspective. A more inclusive document on North Carolina's Estuarine Erosion by Stanley R. Riggs will be available from the N.C. Division of Coastal Management and North Carolina Sea Grant for those who wish to read about these concepts in more detail.

Using this guide, public property managers and private property owners should be able to characterize specific sections of estuarine shoreline and, in Chapter 4, determine the erosion potential. This guide and three others — which are available from North Carolina Sea Grant — can provide the tools to understand and live with our dynamic estuarine shorelines.

Table 1.1. Potential Land Loss in Northeastern N.C.

Estimates of potential land loss in the NE coastal region of North Carolina over the past 25 years in response to ongoing sea-level rise and estuarine shoreline recession based upon analysis and integration of data from the USDA (1975) and Riggs et al. (1978) studies

SHORELINE TYPE	AVG RATES OF EROSION	MILES & % MAPPED	ANNUAL LAND LOSS ON 1,593 MILES MAPPED	TOTAL ESTIMATED LAND LOSS FOR NE N.C. 1975–2000
• Sediment Bank				
Low	2.6 ft/yr	471 mi (30%)	149 acres/yr	11.6 mi^2
High	1.9 ft/yr	111 mi (7%)	25 acres/yr	2.0 mi^2
Bluff	2.1 ft/yr	21 mi (1%)	5 acres/yr	0.4 mi^2
• Organic Bank				
Swamp Forest	2.1 ft/yr	110 mi (7%)	28 acres/yr	2.2 mi^2
Marsh	3.1 ft/yr	880 mi (55%)	330 acres/yr	25.8 mi^2
TOTAL LAND LOSS			**537 ACRES/YR**	**42.0 MI^2**

* *This assumes that Riggs et al. (1978) mapped 50% of the estuarine shorelines in NE North Carolina. These numbers are on the conservative side since most of the shorelines in Pamlico Sound were not mapped or included in the data base, and Pamlico Sound has the highest rates of shoreline erosion.*

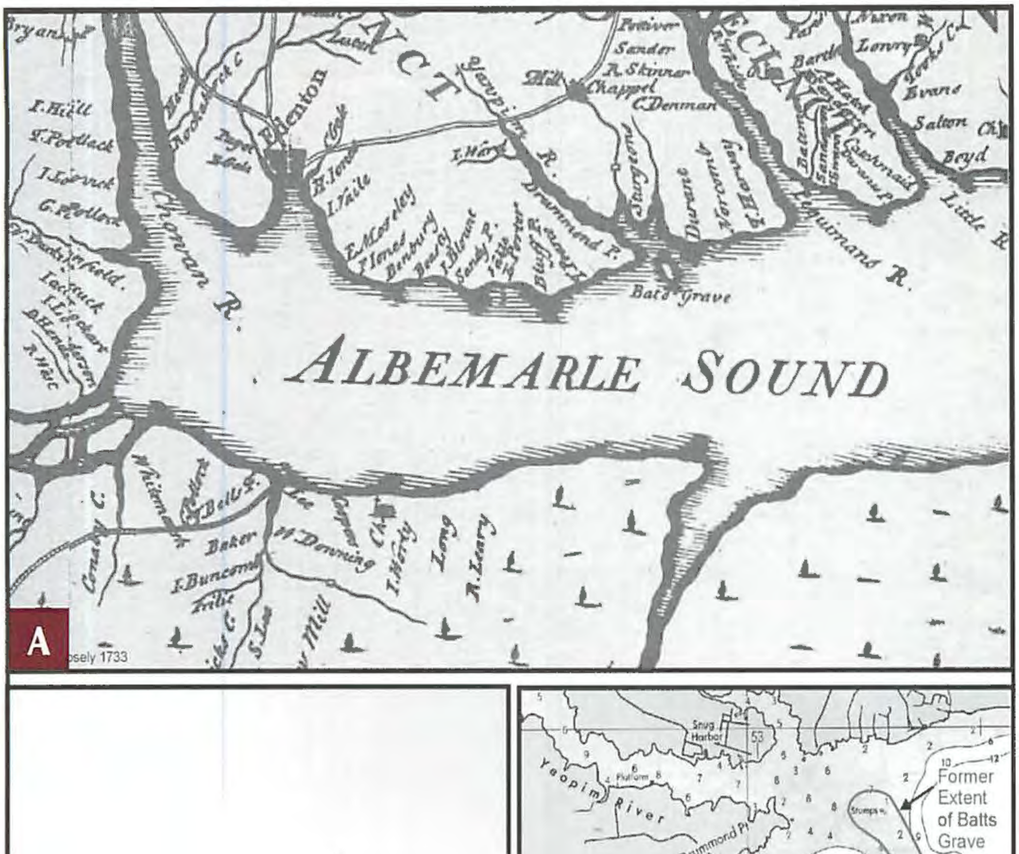


FIGURE 1.1. *Map and photo series showing the demise of Batts Island at the mouth of the Yeopim River in Albemarle Sound.*

Panel A. *The Moseley map of 1733 (Cumming, 1966) refers to the island as Batts Grave.*

Panel B. *Photograph in the early 1970s showing a lone cypress skeleton marking the final demise of the island.*

Panel C. *Portion of the US National Oceanographic and Atmospheric Administration (NOAA) Nautical Chart 12205, Page E, 1976, showing the former location of Batts Grave. Some areas represent less than 6-foot water depth. The arrow indicates the former location of Batts Grave, which is the seaward extension of Drummond Point. As sea level rises, water floods onto the land and wave energy causes the shoreline to recede by erosion.*

Panel D. *Photograph in the early 1990s showing the bouy that marks the shallow shoal remnants of Batts Grave.*

Chapter 2: Estuarine Shorelines

DEFINING THE ESTUARINE SHORELINE

Wherever estuarine water intersects the irregular topography of the land surface, there is a shoreline. In some places, this line of intersection occurs along steeply or gently sloping land underlain by older sediments and rocks. In other places it occurs on low, flat land dominated by the growth of marsh grasses or swamp-forest trees. This shoreline fluctuates mildly in response to both astronomical and wind tides and severely during storm tides. These changes in water level cause the actual line of shore to move up and down, thus producing a shore zone that extends over an area determined by the topography and geometry of the adjacent land surface.

The shore zone is an environment defined by highly variable physical energy conditions, ranging from dead calm water to the extreme wave and tide conditions associated with storms. The shore zone transfers the physical energy of waves, tides and currents to the land. This results in the dynamic processes of erosion and shoreline recession, sediment transport and deposition, as well as the formation of scarps and beaches. Each new input of energy — such as a storm event — causes the shoreline to respond and change over time. This is a natural function of shorelines — to absorb the physical energy occurring at the contact between water and land.

An estuarine sandy beach is an example of a shoreline. It is not only important for swimming enjoyment, but also absorbing wave energy. For a sand beach to form on a given shoreline, three general conditions must be met:

- adequate wave energy;
- a low, sloping ramp for the beach to perch upon at the shoreline; and
- an adequate supply of sand available for waves to build a beach.

Most sand for mainland estuarine shoreline beaches within North Carolina comes from the erosion of the adjacent sediment bank. If no sand exists in the sediment bank, or if it is withheld by a structure such as a bulkhead, there is no sand beach.

Each estuarine shoreline has a unique response to the amount and type of energy it absorbs, the geometry of its adjacent land surface and sea-level rise. Thus, erosion rates vary widely. Herein lies the human dilemma. The rates of change may occur in time frames of days and years in severe contrast to the expectations of permanence and economic values placed upon waterfront properties.

The major types of estuarine shorelines are identified in Tables 2.1, 2.2 and 2.3 (pages 24 and 25), which summarize the characteristics of estuarine shorelines, as well as erosional and accretionary status.

Shoreline erosion is an ongoing, natural process within the North Carolina estuarine system resulting from the short- and long-term evolution of the coast. While various methods are available to combat erosion and land loss, none are permanent solutions, and all have significant environmental tradeoffs. Recognizing and understanding the complex causes and dynamic processes involved in shoreline erosion is the first step toward minimizing the impact of erosion and managing shoreline resources and economic investments. Ultimately, to both preserve coastal estuarine resources and maximize human utilization, long-term management solutions to the problems of estuarine shoreline erosion problems must be in harmony with the dynamics of the total coastal system.

Facing page: This actively eroding low sediment-bank estuarine shoreline is along the Pungo River.

TYPES OF ESTUARINE SHORELINES

North Carolina estuaries result from the recent, post-glacial rise in sea level and resulting flooding up the stream valleys of the coastal plain drainage system. Tables 2.1, 2.2 and 2.3 (pages 24 and 25) outline the general shoreline types that characterize the estuarine perimeters. The estuarine shorelines occur either along the banks of the drowned-trunk and tributary rivers, or along the backside of the barrier islands.

To better understand the coastal system, it is imperative to understand the basic geologic controls that divide North Carolina's coast into two provinces (Figure 2.1). The southern coastal province extends from the South Carolina border to Cape Lookout. The dominant geology consists of very old, hard rocks, associated with a structure called the Carolina Platform, resulting in an erosional topography with relatively steep slopes. The northern coastal province extends from Cape Lookout to the Virginia border and is underlain by younger, softer or unconsolidated, sediments, resulting in a depositional topography with very low slopes. Table 2.4 (page 26) summarizes the basic differences between the two provinces.

The southern province is characterized by an average slope of 3 feet/mile compared to 0.2 feet/mile in the northern province. Thus, rising sea level floods the provinces quite differently, producing different kinds of barrier island/inlet systems and adjacent estuaries. The steeper slopes of the southern province produce short, stubby barrier islands with 18 inlets and narrow back barrier estuaries. The gentle slopes of the northern province produce long barrier islands with only four inlets and an extensive sequence of broad, drowned-river estuaries. The northern barrier islands project seaward, forming the famous Outer Banks — a sand dam that semi-isolates the Albemarle-Pamlico estuarine system from the Atlantic Ocean.

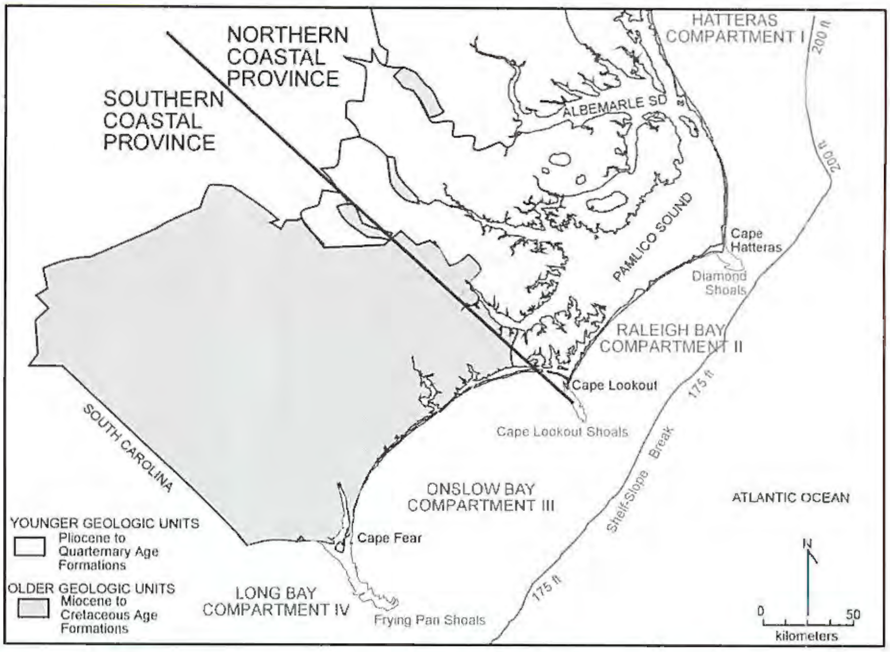


FIGURE 2.1. Generalized geologic map of the North Carolina Coastal Plain showing the two coastal provinces and the four geomorphic compartments of the North Carolina coastal system. These cuspate embayments are defined by the classic Carolina capes and their associated cross-shelf sand shoals.

North Carolina is characterized by trunk and tributary types of estuaries. Trunk estuaries refer to drowned river valleys, which are perpendicular to the coast. In the northern province, these include the four major piedmont-draining rivers: Chowan and Roanoke rivers forming the Albemarle Sound estuary, the Tar River forming the Pamlico River estuary, and the Neuse River becoming the Neuse River estuary. The southern province has small black-water rivers that originate in the coastal plain and also form a series of small, coast-perpendicular, drowned river estuaries, such as the North, Newport, White Oak and New River estuaries. The much larger Cape Fear River drains the piedmont and empties directly into the Atlantic Ocean.

Flowing into the trunk estuaries is a network of drowned-tributary streams that are like capillaries flowing into larger arteries of the human circulatory system. These tributary estuaries have sediment-bank shorelines along the outermost portions that have open expanses of water and waves. Up the tributaries, the sediment banks are fronted first by fringing marshes that increase in width to become broad platform marshes, and

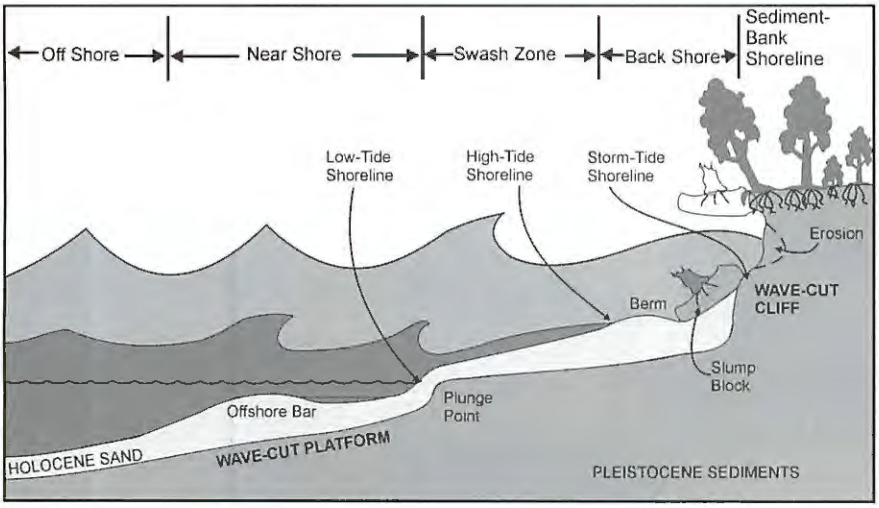


FIGURE 2.2. Schematic model of a sediment-bank shoreline showing the following geomorphic features. 1) A wave-cut scarp and platform have been eroded into older sediment units with a strandplain beach perched on the platform. 2) Three different water levels and wave sizes that do the work of shoreline erosion, beach building, and beach maintenance. 3) The process of eroding and undercutting the bank top during high storm tides and subsequent slumping and reworking of slump blocks to produce the beach sediments.

ultimately grade into the riverine floodplain swamp forest.

These marshes extend to fill much of the uppermost reaches of the estuary and finally grade into riverine, floodplain swamp forests in the headwater portions of the stream. Black needlerush dominates the platform marshes, due to decreased tidal range and generally lower salinity within the upper reaches. Tributary marshes become flooded during storms, absorbing much of the storm-wave energy, and thus protecting adjacent land areas.

Four basic categories of shorelines occur within the North Carolina estuarine system (Table 2.5, page 27): (1) sediment-bank shorelines; (2) organic shorelines; (3) combination shorelines; and (4) back-barrier shorelines. Since each shoreline type erodes at different rates and in response to specific water levels and types of energy, it is important to first recognize the type of shoreline on a given property.

Sediment-Bank Shorelines

Sediment-bank shorelines are subdivided based upon bank height: bluff, high bank and low bank (Table 2.5, page 27). Most sediment-bank shorelines are eroded into older sand and clay sediment units. If the eroding sediment bank contains adequate sand supplies, a sandy beach will form as a thin and narrow feature delicately perched on top of a wave-cut platform (Figure 2.2). Sediment-bank shorelines consist of a gently seaward sloping, wave-cut platform below water level, and the associated steeply sloping, wave-cut scarp on the landward side of the beach.

Bluffs, greater than 20 feet, and ***high banks***, between 5 feet and 20 feet, occur primarily in the westernmost portion of the estuarine system. They are the least abundant types of shorelines, but are in the greatest demand for home-site development (Figure 2.3). Bluffs generally consist of tight clay and moderately to tightly cemented sandstone near their base with unconsolidated water-bearing sands and clayey sands above. Their bases tend to resist undercutting better than those of low-sediment banks. Where groundwater seeps out of the bluffs, the bluffs often slump off blocks of sediment, which may supply more sand or encourage some fringing plant growth. High banks tend to have well-developed sand beaches, compared to low-bank shorelines.

Bluffs and high banks are generally eroded during severe storms when onshore waves overstep the sand beach and break directly against the bank. The undercut bank eventually slumps. If longshore or offshore currents are effective at removing sediment from the base of the bank, erosion rates can be quite high. Vegetative debris — consisting of stumps, tree trunks and branches — serve to dampen wave action to some degree and act as a trap for eroded sediments.

Low banks, less than 5 feet, are the most abundant type of sediment-bank shoreline, and are the dominant type in the eastern portions of estuaries as the elevation of uplands decreases (Figure 2.4). These shorelines generally consist of unconsolidated sediment on top of a clay bed, which occurs at or slightly below sea level. Clay beds usually occur just below the thin surface sands in the offshore area and control the bottom slope and water depths.

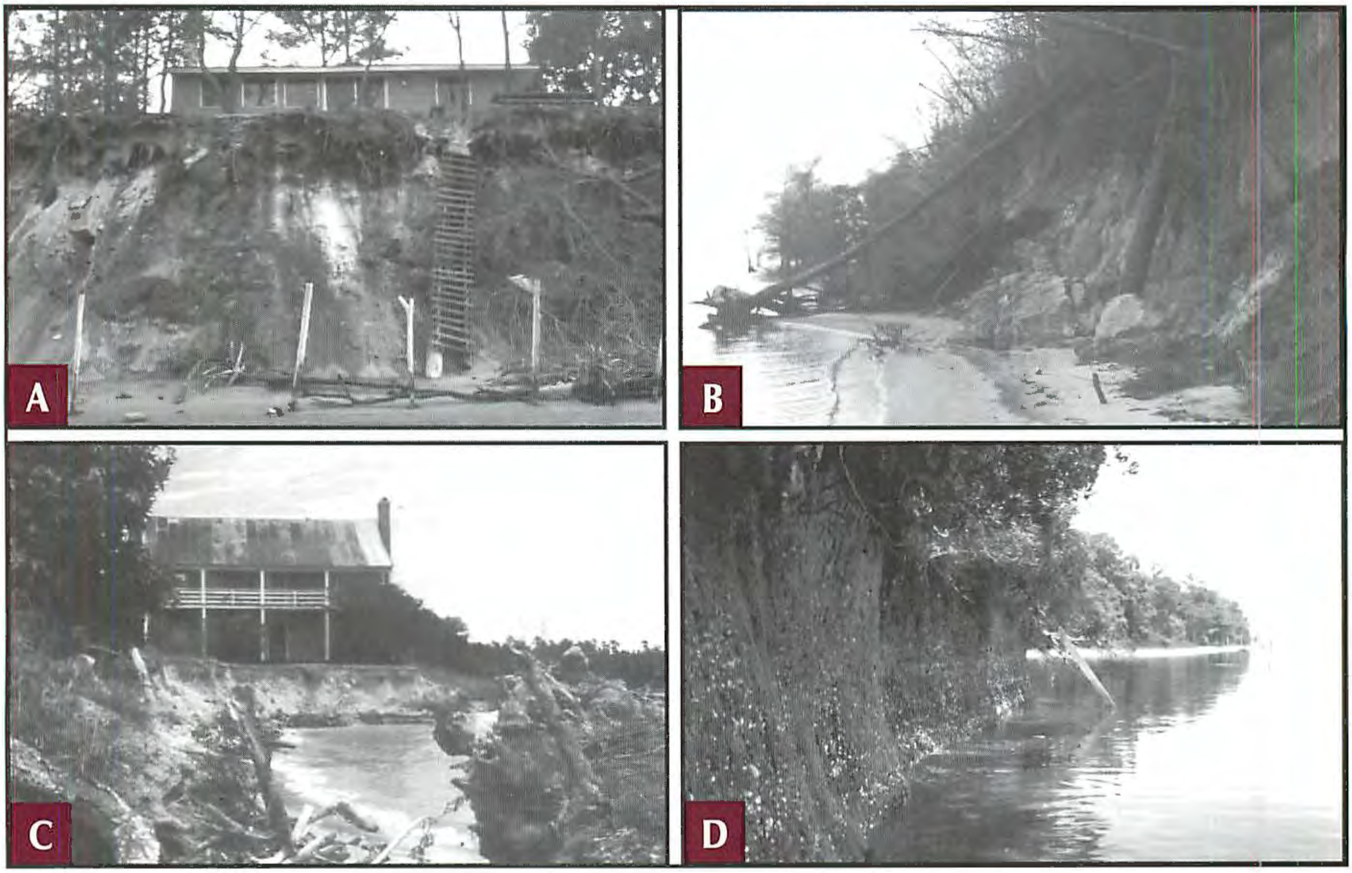


FIGURE 2.3. Photographs of eroding bluff and high-bank estuarine shorelines. ***Panel A.*** *An actively eroding bluff-bank estuarine shoreline. Due to the very sandy composition of the bluff, the wave-cut scarp is dominated by slumping, which is continuously reworked into an extensive strandplain beach.* ***Panel B.*** *An eroding high-bank estuarine shoreline. Notice that erosion is not taking place at the time the photograph was taken when no winds were blowing, and the water level was normal. Large slump blocks with trees on top have collapsed onto the beach and are being reworked into an extensive strandplain beach. The trees ultimately will be laid down and act as natural groins to help trap and hold the beach sands in place.* ***Panel C.*** *An eroding high-bank estuarine shoreline with a colonial farm house that was not built on the water's edge. Notice that the size of the strandplain beach decreases as the height of the wave-cut scarp decreases.* ***Panel D.*** *A very slowly eroding high-bank estuarine shoreline composed of a very tight, fossiliferous, blue mud. Since this is a mud that is slowly receding, there is not an adequate source of sand to build a strandplain beach.*

Low banks erode more quickly than high banks due to minimal sand supplies and the lack of wide sand beaches. Vegetative debris can act as natural groins, which trap minor amounts of sand and occasionally form a nucleus where clumps of marsh grass can grow. If the scattered marsh grasses can become established and if wave energy is not too severe, grasses may expand to produce a fringing marsh, decreasing the rate of shoreline recession.

In summary, most high-bank and low-bank shorelines are eroding. The rates depend upon the geographic location within the estuarine system, exposure to wave energy, and extent of vegetative cover. Erosion rates are extremely variable, ranging from a few feet per decade in the innermost trunk estuaries and small tributary estuaries up to 10 feet per year for exposed low-bank shorelines in the middle and outer estuarine reaches. The shorelines around

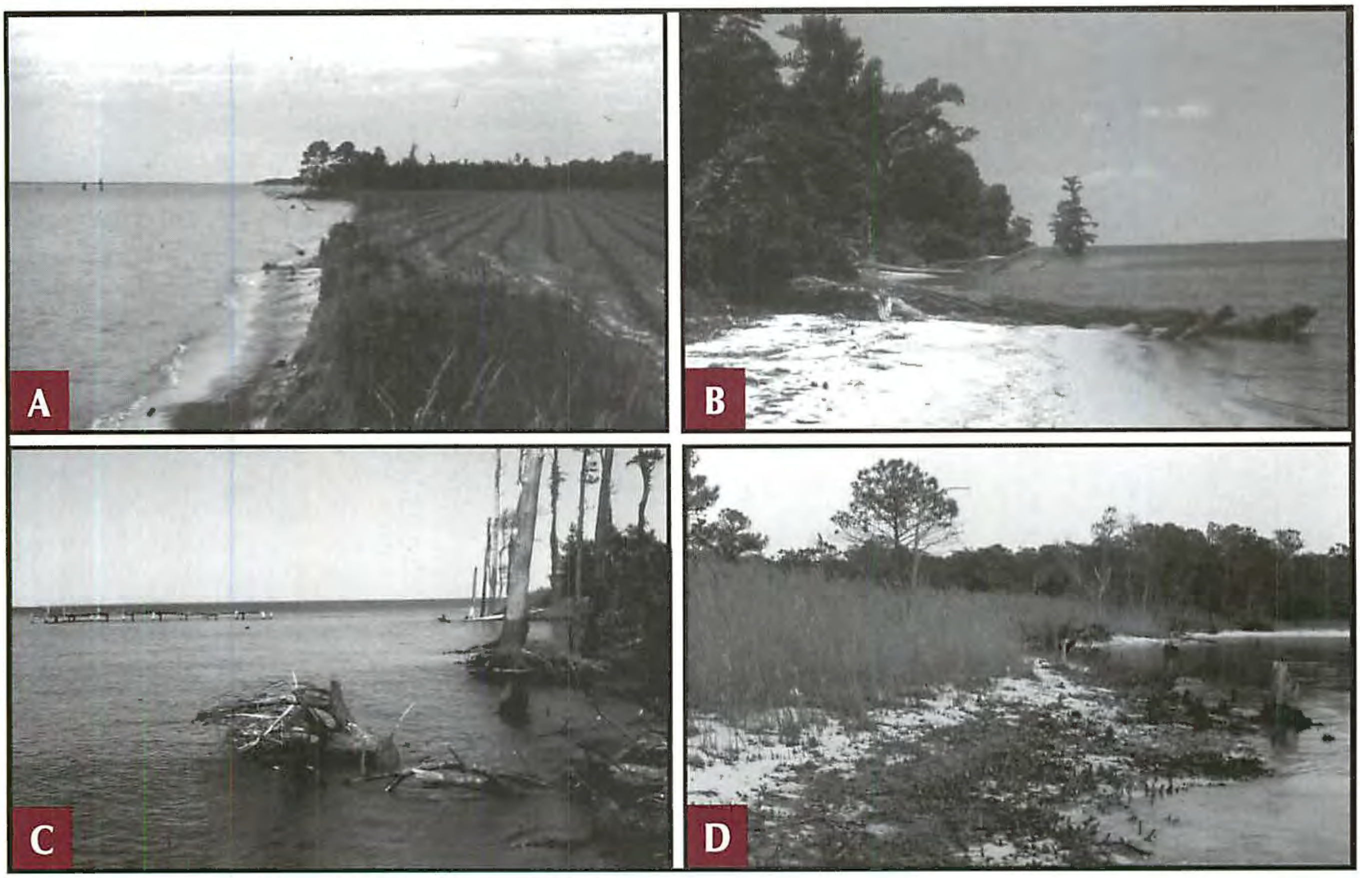


FIGURE 2.4. Photographs of several types of low-bank estuarine shorelines. ***Panel A.*** *An actively eroding low-bank estuarine shoreline. The size of the strandplain beach has decreased significantly as the height of the wave-cut scarp has decreased. Notice that the rate of erosion is so high that the tractor turning area has been eliminated since the crop was planted.* ***Panel B.*** *A segment of low-bank shoreline that is stabilized by a heavy growth of vegetation. The sand that forms the strandplain beach was derived from adjacent properties after the banks were cleared for development. Notice how the amount of sand dramatically diminishes into the background and the role of tree trunks as natural groins in trapping and holding the beach sand.* ***Panel C.*** *An actively eroding low-bank shoreline that is too small to produce a wave-cut scarp, and there is no sand available in the bank to produce a strandplain beach. Consequently, the muddy sediment is slowly washed out from around the trees, leaving the ghosts of pine forest and their many stumps standing in the shallow water.* ***Panel D.*** *A very low-bank shoreline that is being converted to a freshwater marsh in response to the ongoing rise in sea level. The soil upon which the pines and live oak were growing has been buried by a thin layer of peat produced by the freshwater grasses. Ongoing shoreline recession has produced a minimal amount of sand for the development of a minor strandplain beach and has left the stumps exposed in the shoreface.*

the Pamlico and Albemarle sounds often have erosion rates that exceed 15 feet per year. Since most shoreline erosion takes place in direct response to high-energy storms, the amount of recession at any location varies.

Organic Shorelines

Organic shorelines are subdivided into marshes and swamp forests. Vegetation consists of water-tolerant trees, shrubs and grasses that grow at the land/water interface and are able to endure temporary but not permanent flooding. Coastal marsh shorelines occur in waters that range from fresh to salt water, whereas swamp-forest shorelines occur only in freshwater wetlands associated

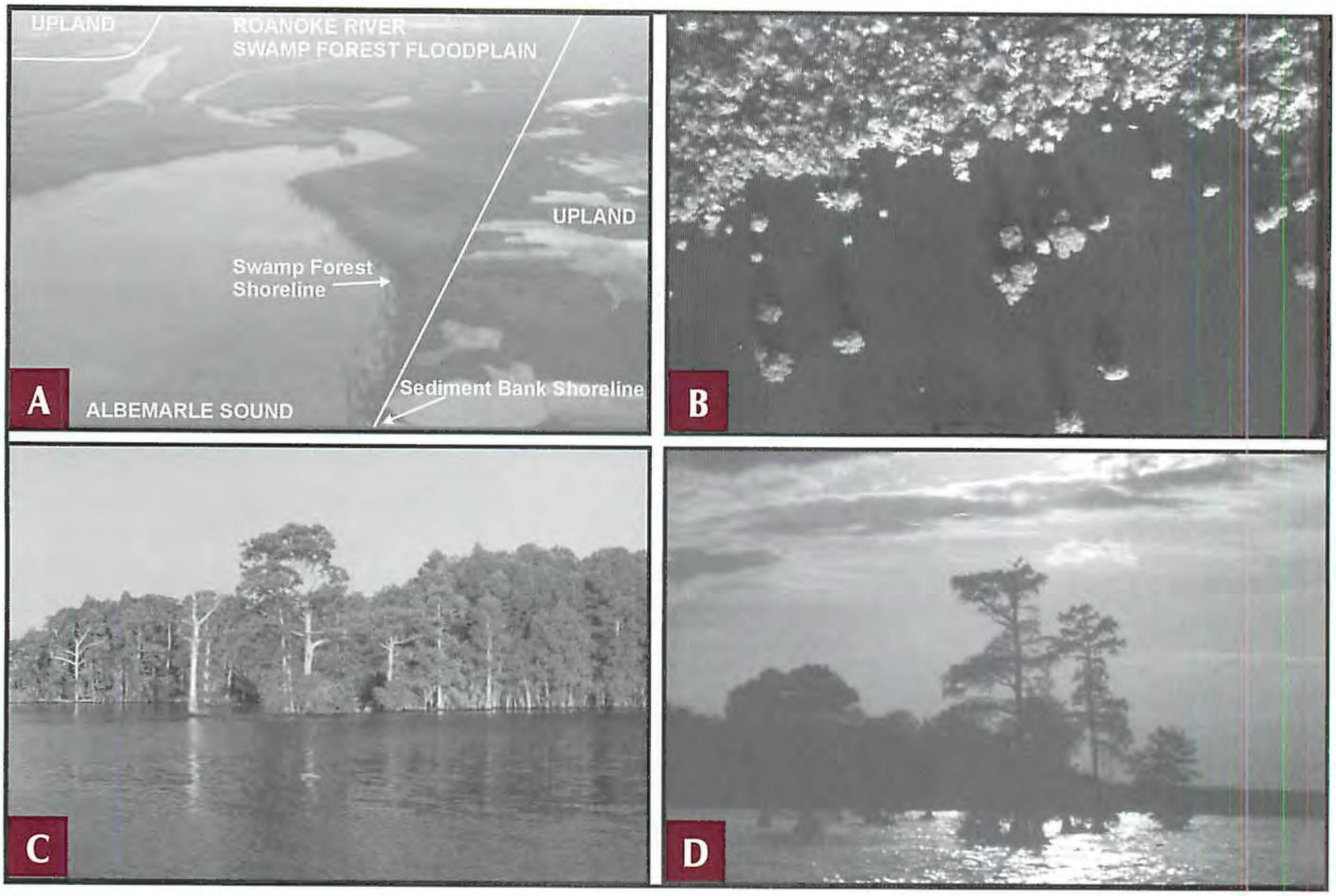


FIGURE 2.5. Photographs of swamp-forest shorelines in the riverine/estuarine transition zone of the Roanoke River and Albemarle Sound. ***Panel A.*** *An oblique aerial photograph of the transition zone between the Roanoke River swamp-forest floodplain and Albemarle Sound estuary. Notice the abundant cypress trees that can tolerate permanent drowning more readily than other species. Species that are less tolerant of flooding, such as the swamp maple and gum, die off fairly quickly as sea level rises and leaves the cypress standing alone in the water as the shoreline slowly recedes. Notice how the floodplain is totally eroded on the seaward side where the upland comes into direct contact with the estuary to produce sediment-bank shorelines.* ***Panel B.*** *A vertical aerial photograph looking straight down on a receding swamp-forest shoreline with abundant cypress trees left standing out in the shallow estuarine waters.* ***Panel C.*** *A water-level view of the photograph in Panel B.* ***Panel D.*** *One of the classic views that characterize the cypress stands within the upper reaches of North Carolina's drowned river estuaries.*

with riverine floodplains or pocosins. All organic shorelines are characterized by peat sediment, which is composed of decayed plants and other organic matter with varying amounts of intermixed fine sand and mud, depending upon the specific location within the estuarine system.

Swamp-forest shorelines are dominated by wetland trees and shrubs (i.e., cypress, gum, swamp maple, bay, wax myrtle, etc.) and have two occurrences. They occur within the freshwater, riverine floodplains of the uppermost portions of trunk and tributary estuaries (Figure 2.5). They also occur in the outermost portions of trunk and tributary estuaries where low freshwater wetlands (i.e., pocosins) are intersected by the eroding shoreline.

As sea level rises, the lower portions of riverine floodplains become permanently flooded, causing the shrubs and trees to become stressed and die by drowning and producing a swamp-forest

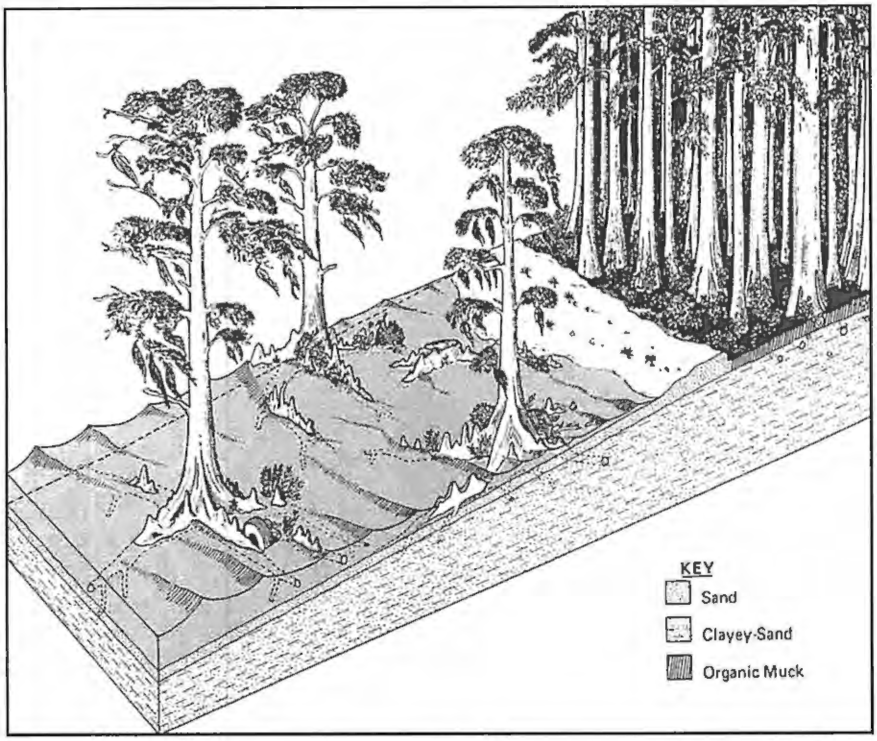


FIGURE 2.6. Schematic model of a swampforest-peat shoreline (modified from Bellis et al., 1975). This type of shoreline has two general occurrences. Their primary occurrence is in the transition zone where the riverine floodplain intersects mean sea level along the innermost portion of drowned river trunk and tributary estuaries. Within the outer portions of the estuarine system, swamp-forest-peat shorelines occur wherever shoreline erosion intersects a former upland pocosin. This is a common occurrence in the low lands of the outer counties such as Currituck, Dare, Hyde, Tyrrell, Pamlico and Carteret.

shoreline (Figure 2.6). The vegetation that is least tolerant of flooding dies off first. This leaves the most tolerant, the cypress, to stand in open water beyond the shoreline (Figure 2.7). The result is one of the most characteristic and beautiful sights within the North Carolina estuarine system. Ultimately, the cypress die and are blown over by storms or undercut by the eroding peat bank along the outer edge of the floodplain as the swamp-forest shoreline slowly recedes. Usually it is difficult to tell where the actual shoreline is because the treeline does not necessarily follow the land-water interface (Figure 2.7).

In the northern province, vast upland wetlands known as pocosins become intersected by the receding coastline (Figures 2.7C and 2.7D). Regardless of whether the pocosin consists of cypress and gum, or shrub, bay, and pine, the receding shoreline is characterized by the ghost remnants of drowned trees and extensive stumps and root masses scattered through the shallow nearshore waters (Figure 2.7D).

A cypress fringe occurring in front of a sediment bank (Figures 2.8C and 2.8D) reduces erosion. Functionally, the broad fluted base and complex knee structures of cypress trees act as natural bulkheads, dissipating wave energy, slowing erosion, and trapping available sediment. The irregular distribution of the trees allows some wave energy to pass through the trees, causing slow erosion and sediment production from the bank. This process forms a beach, which is critical to the overall dynamics and energy absorption. Maintaining this cypress fringe can help landowners protect upland property.

Marsh Shorelines occur throughout the estuaries and are dominated by emergent grasses. The marsh grades up to a transition zone composed of wax myrtle, marsh elder and cotton bush and into the adjacent upland composed of pines and hardwoods (Figure 2.9). Freshwater marshes occur in the innermost riverine and estuarine regions and are dominated by cattails, bulrushes and reeds. The freshwater marshes grade seaward into brackish marshes dominated by either saltmeadow cordgrass or black needlerush, depending upon whether the estuary is characterized by high- or low-salinity water, respectively (Figure 2.9). Within the inner and middle estuarine system, freshwater and brackish marshes may either occur as narrow fringing marshes in front of and protecting segments of sediment-bank shorelines, or may completely fill small tributary estuaries.

In the outer estuarine regions of the northern province, the slope of the upland is minimal as it approaches sea level. Also, these estuaries are characterized by few inlets through the barriers, and strong wind tides cause irregular fluctuations of water level. Thus, the marshes are generally wave dominated with irregular

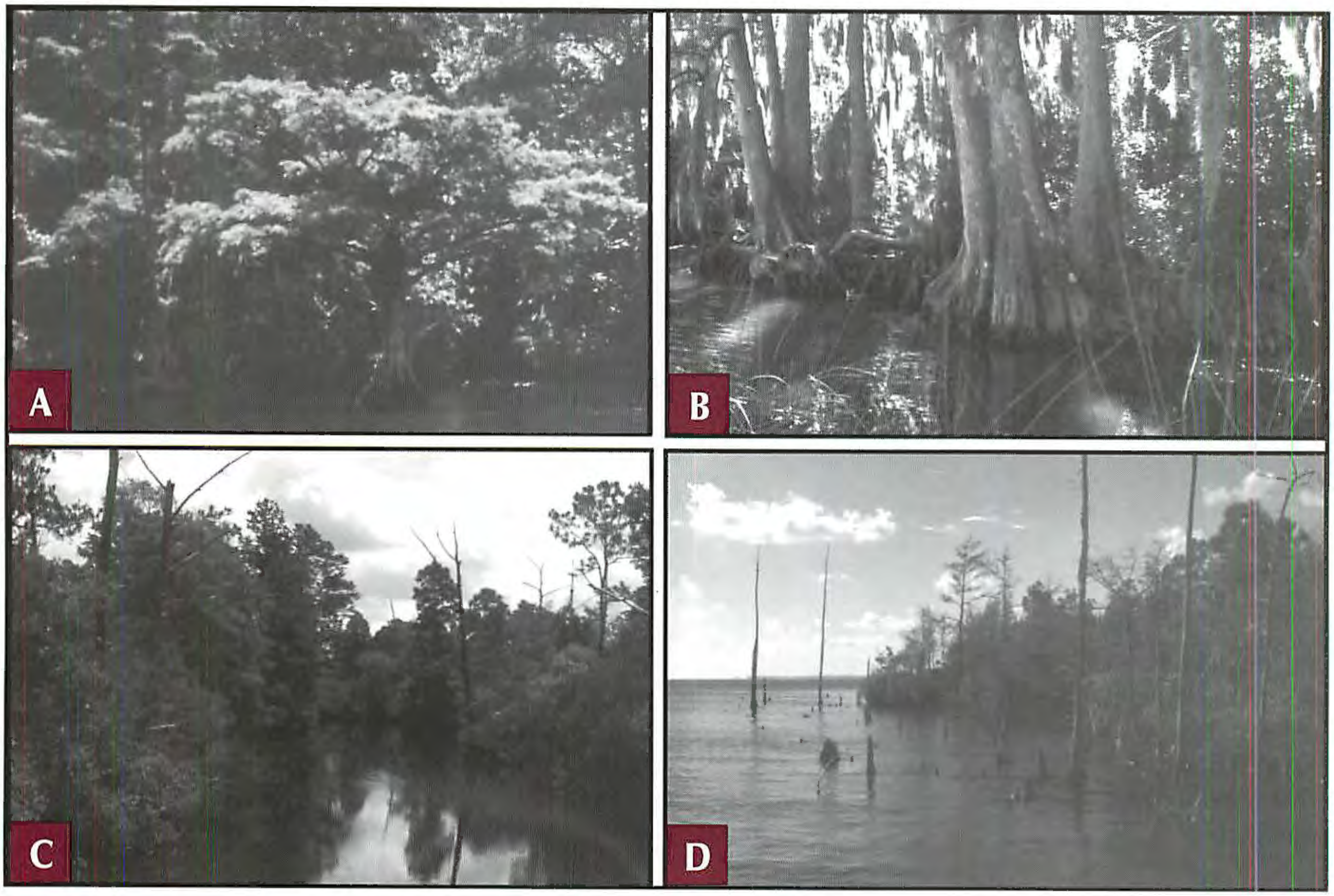


FIGURE 2.7. Photographs of vegetatively bound swamp-forest shorelines in the headwaters of small tributary estuaries and in the outer estuaries where the receeding shoreline has intersected pocosin swampforests. ***Panel A.*** *A vegetatively bound swamp-forest shoreline that displays little to no shoreline recession taking place.* ***Panel B.*** *Estuarine shoreline dominated by a massive bulkhead-like zone of cypress trees that effectively protect the shoreline from day-to-day erosional processes.* ***Panel C.*** *The estuarine headwaters of a tributary stream are heavily dominated by vegetation. Rising sea level is causing a change in vegetation from less wet to more wet adapted species as evidenced by the scattered and still-standing dead pine trees.* ***Panel D.*** *Photograph of a pocosin swamp-forest shoreline where the receeding shoreline has intersected a swamp system perched on a low upland area. Wave action erodes out the enclosing peat sediment, leaving the ghost trees and stumps standing out in the shallow waters. This type of shoreline occurs primarily in the lowland regions of the outer estuaries in Currituck, Dare, Hyde, Tyrrell, Pamlico and Carteret counties.*

storm-tide flooding. This situation determines three basic characteristics of the northern marshes. First, they tend to occur as vast and spectacular wetland habitats that form as broad, flat platforms with few if any tidal creeks (Figure 2.10). Second, the marshes are dominated by black needlerush with occasional narrow outer rims of one or more species of cordgrass. Third, the outer shoreline in any area with a significant fetch is in a destructive or erosional phase (Figure 2.11).

Marsh shorelines are characterized by the accumulation of thick beds of fairly pure organic matter or peat deposited in response to rising sea level. If the outer marsh perimeter is exposed to large stretches of open water with high-wave energy, the peat sediment is actively eroded producing vertical scarps or cliffs that drop abruptly into 3 to 8 feet of water (Figure 2.11). The scarps are generally characterized by severe erosional undercuts into the soft peat below the

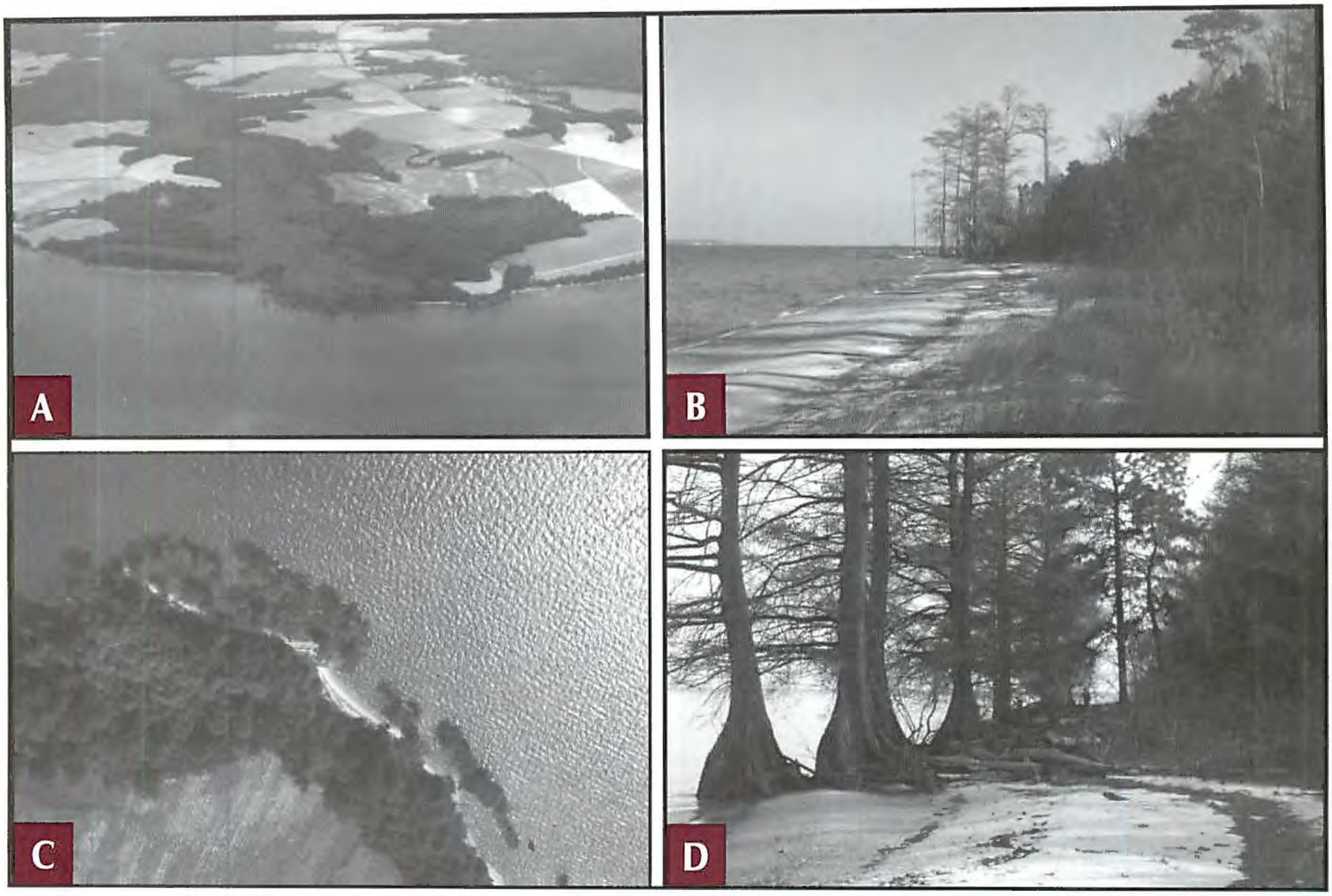


FIGURE 2.8. Photographs of shorelines dominated by cypress headlands and cypress fringes. ***Panel A.*** *An oblique aerial photograph showing the differential erosion rates of a tributary stream and associated swamp-forest floodplain as it enters the Albemarle Sound and the adjacent sediment-bank shorelines. The swamp-forest vegetation drowns and receeds at slow rates leaving the cypress standing in the shallow waters as the adjacent sediment-bank shoreline receeds more rapidly.* ***Panel B.*** *A ground view of a similar cypress headland in the Neuse River estuary. The cypress form a headland that acts as a large-scale groin, trapping an extensive strandplain beach in front of the eroding sediment bank in both the upstream and downstream segments.* ***Panel C.*** *An aerial photograph looking vertically down upon a sediment-bank shoreline with a cypress fringe in front of an eroding sediment-bank shoreline in the Chowan River.* ***Panel D.*** *A ground view of a similar cypress fringe fronting a bluff shoreline in the Albemarle Sound. The cypress have helped trap sand and build the strandplain beach, as well as partially protect the adjacent bluff on the right side of the photo. The protection has allowed a significant growth of vegetation that further protects this shoreline.*

extremely tough modern root mat. With continued undercutting, the overhang surges with each wave until large undulating peat blocks finally break off, supplying eroded organic detritus and large peat blocks to the adjacent estuarine floor. Erosion of marsh-peat shorelines is one of the major sources of fine organic detritus that forms the black organic-rich mud sediments within the estuarine central basins.

In the southern province, two general types of marshes occur in front of the sediment-bank shorelines in a continuum from narrow fringing marshes to vast platform marshes. Marsh cordgrass dominates the areas of moderate to high salinity, while black needlerush dominates in moderate- to low-salinity regions. Up the tributary streams, marshes tend to increase in width and

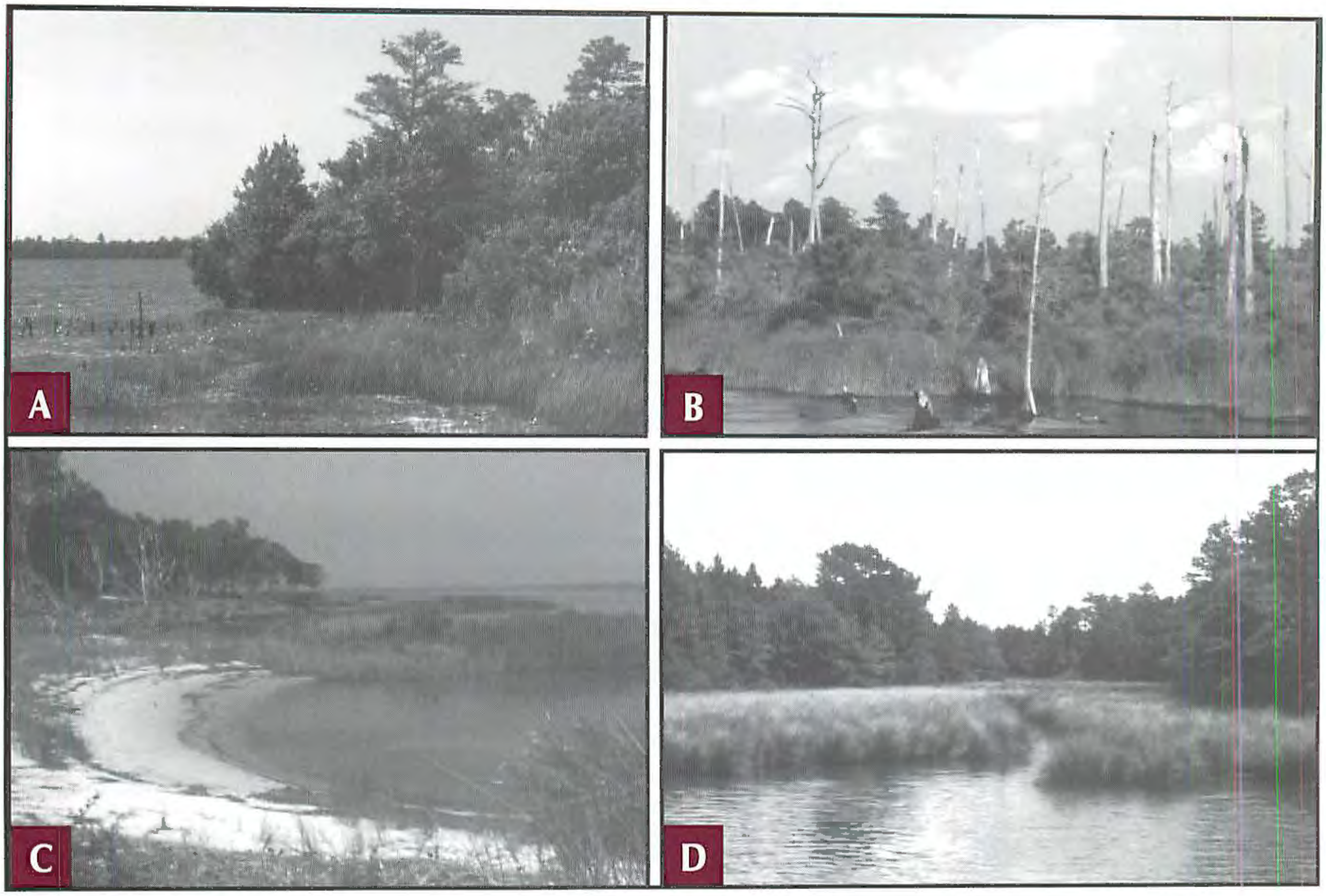


FIGURE 2.9. Photographs of fresh to brackish, irregularly flooded, fringing marsh shorelines. ***Panel A.*** *A highly vegetated, low-bank shoreline with a fringing marsh composed of freshwater grasses.* ***Panel B.*** *A highly vegetated, very low-bank shoreline with a fringing marsh composed of freshwater grasses. The effects of ongoing sea-level rise are obvious as the old-growth pine are stressed and ultimately die by drowning and are replaced by more water-tolerant transition zone shrubbery and finally by the marsh grasses.* ***Panel C.*** *The low-bank shoreline, dominated by upland vegetation, is fronted by a broad strandplain beach with a fringing marsh composed of cordgrass and transition zone plants. The sand that forms the beach was derived from an eroding shoreline in back of the photographer. Notice the interdependence between the cuspate geometry of the beach and growth of marsh grasses. The marsh grows on the shallow sands on the edges of the cusps, but also traps additional sediment, causing the increased growth of the cuspate structures.* ***Panel D.*** *The shallow waters of this tributary estuary have developed a wide fringing, brackish water marsh composed of black needlerush. The fringing marsh has completely filled the shallow perimeter platform to the channel, which is the original stream channel that concentrates the water flow and is too deep for growth of the marsh grass.*

become broad platform marshes that grade into upstream swamp forests. These broad marshes flood during storms, absorbing much of the wave energy and thus protecting adjacent land areas.

The landward side of these marshes is usually in a constructive mode, with the marsh migrating onto the adjacent upland areas as sea level rises (Figure 2.11). Thus, as the marshes are eroded on the estuarine side, they are generally expanding on the landward side. Rising sea level causes the groundwater level to rise, stressing and finally drowning the lowermost line of upland vegetation. The marsh accumulates peat sediment to allow the vertical growth of grasses to keep up with sea level. This vertical

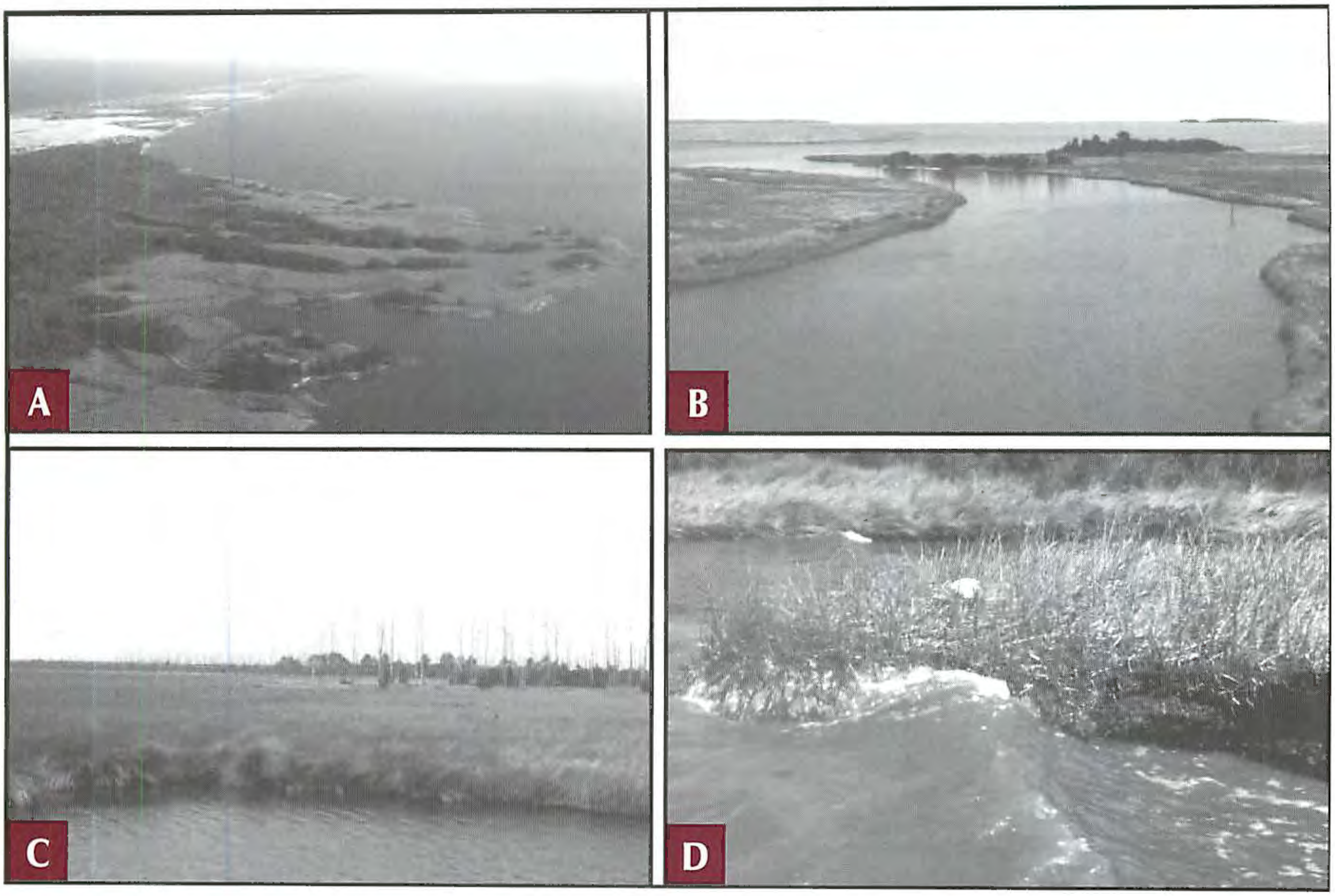


FIGURE 2.10. *Photographs of low-brackish, irregularly flooded, and wave-dominated, platform marsh shorelines of the northern province.* ***Panel A.*** *An oblique aerial photograph shows the broad platform marsh composed of black needlerush encroaching upon the back side of the high and wide barrier island behind Nags Head Woods. Notice the elongate ridges and small, circular hammocks scattered through the marsh and characterized by dark green upland vegetation. These hammocks are the high points on the paleotopographic surface that are being drowned and buried by the marsh in response to ongoing sea-level rise. Jockey's Ridge, an active back-barrier sand dune, is visible in the distance.* ***Panel B.*** *An oblique aerial photograph shows a portion of the broad expanse of black needlerush marsh in the Cedar Island National Wildlife Refuge. Notice 1) the bright rim of cordgrass marsh that forms the outer zone adjacent to the waterway and 2) hammocks in the marsh characterized by dark upland vegetation.* ***Panel C.*** *Ground-view photograph of a broad, black needlerush platform marsh at mean water level. The marsh shoreline in the forground has a 3- to 5-foot deep vertical erosional scarp below the water with an extensive undercut just below the water surface. Notice in the distance the obvious effects of ongoing sea-level rise as all the older growth pine became stressed and died by drowning and have been replaced by more water-tolerant transition zone shrubbery.* ***Panel D.*** *A close-up view of an eroding platform marsh shoreline. The surging wave energy erodes the softer peat below the exposed peat ledge, which consists of a dense root mass of the modern cordgrass marsh. As the undercut becomes more extensive, the surface root mass begins to move with each wave until a large block finally breaks off.*

growth results in the marsh encroaching upon the upland and burying the old stumps and logs in the processes (Figure 2.11). Landward expansion of the marsh continues until the upland slope becomes too steep, or the upland is bulkheaded for development. Then, marsh expansion is terminated and future rise in sea level will result in a net loss of marsh habitat.

The presence of the fringing marsh grasses retards erosion of associated beaches and sediment banks by accumulating and stabilizing beach sediments. However, if the offshore slope is increased by dredging for navigation channels, fringing marshes quickly become subjected to increased erosion from the wakes of boats using the channel. As either the slope of the land decreases or the degree of protection increases, the narrow fringing marsh expands to become an extensive platform marsh. Platform marshes are most extensive in the eastern portions of Carteret and Pamlico counties and include the marshes of the Cedar Island National Wildlife Refuge in northeastern Carteret County. The seaward edges of platform marshes are generally characterized by erosional scarps, which drop abruptly into 1 to 8 feet of water. Some of the most rapid rates of shoreline erosion in the entire estuarine system occur where large fetches interact with the deep-water marsh margins, allowing the soft peat beds underlying the modern marsh root zone to be undercut by waves. Almost all extensive marsh shorelines in the northern province are rapidly eroding. During high tides, storm-wave energy is dissipated as waves are baffled by submerged grasses within the flooded marsh. Thus, these marshes function as important energy-absorbing barriers between the open water and adjacent uplands.

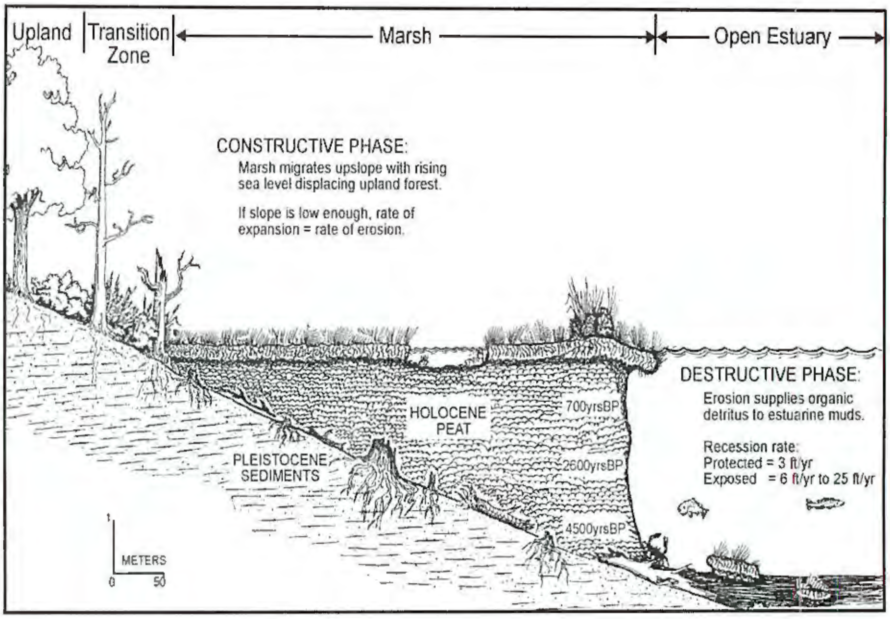


FIGURE 2.11. *Schematic model of a marsh-peat platform shoreline. This type of marsh occurs extensively in the northern province where the astronomical tides are minimal and wind tides dominate. These flat marshes generally maintain a steady-state condition in response to rising sea level. The marsh itself and the landward side is generally constructive as it responds to rising sea level by the vertical accretion of organic matter and contemporaneous migration upslope. Sea-level rise stresses and kills the upland vegetation that is replaced by the rising marsh vegetation systematically burying the upland stumps and logs beneath the rising marsh. High-wind tides flood the marsh, but wave energy is quickly baffled by the marsh grasses. However, low-wind tides allow wave energy to break directly on soft peat beneath the modern root mass, causing severe undercutting of the bank and ultimately breaking off large peat blocks. Thus, the seaward side of the marsh is generally in a destructive phase with recession rates totally dependent upon the fetch, water depth and amount of wave energy. The radiocarbon age dates are from the marshes at Wanchese on the south end of Roanoke Island (Benton, 1980).*

The back-barrier estuaries of the southern province and areas around the inlets in the northern province are characterized by high-brackish salinity and are regularly flooded by astronomical tidal currents. In these regions, saltmarsh cordgrass and salt meadow hay grow along the portions and tops of sloping banks between the mean high tide and high-tide lines. Below the mean tide line and extending into the adjacent tidal channels stretch widespread, low-sloping mudflats and sandflats (Figure 2.12). The lower portions of the marsh and the flats are often covered with vast reefs of oysters. The marsh vegetation grows on the upper portions of these low-sloping ramps, where it actively traps sediment and builds the shoreline out into the estuary.

Combination Shorelines

Combination shorelines are composed of sediment banks and narrow fringes of marshes or swamp forests. This situation is further complicated when a given shoreline is modified by humans who either build structures, add new materials, or alter the landscape geometry. Sediment-bank shorelines with wide sand beaches in the upper reaches of

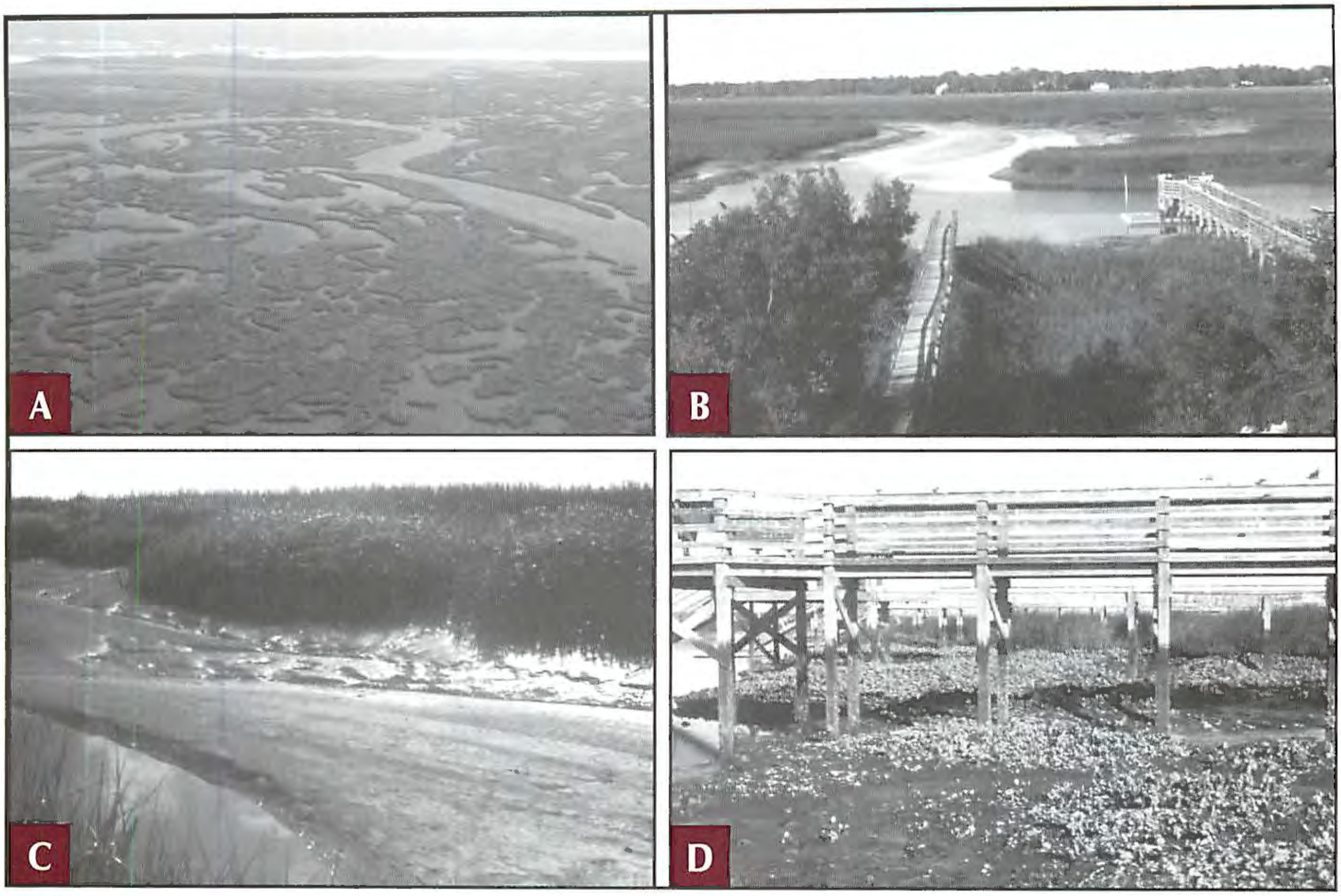


FIGURE 2.12. *Photographs of high-brackish, regularly flooded marsh shorelines and associated tidal mudflats of the southern province.* ***Panel A.*** *An oblique aerial photograph of the extensive cordgrass marsh that fills Topsail Sound behind the simple overwash barrier island in the distance. Since the photo was taken at summer high tide, the tidal creeks are totally filled with water, and all mudflat environments are submerged.* ***Panel B.*** *A groundview of an extensive cordgrass marsh that fills the sound behind Sunset Beach. Since the photo was taken at winter low tide, the tidal creeks are almost empty, and the vast mudflat environments are well-exposed.* ***Panel C.*** *A close-up view of the cordgrass marsh, associated mudflats, and tidal channel in the previous panel.* ***Panel D.*** *A close-up view of the abundant oyster reefs that occur on the mudflats and extend into the lower portion of the marsh in the previous panels.*

trunk and tributary estuaries often contain a fringe of cypress trees (Figures 2.8C and 2.8D). Similar shorelines in the middle to outer estuarine reaches develop marsh fringes in areas where the shoreline is somewhat protected (Figure 2.9B and 2.9C). Organic components along sediment-bank shorelines buffer wave energy and help protect the adjacent shoreline in all but the largest storms.

Low-bank shorelines are extensive in the outer portions of the mainland peninsulas and are frequently dominated by remnant forests of pine stumps in the water. Since pine trees have a deep tap root, the sediment is frequently washed out from around the stump as the shoreline recedes, leaving a ghostly tangle of stumps logs and roots in the shallow offshore (Figure 2.7D). This results in many obstructions that require boaters and swimmers to beware. However, removal of these relict forests will result in the immediate increase in shoreline recession rates.

Likewise, any organic shoreline that has a source of sand can develop a small

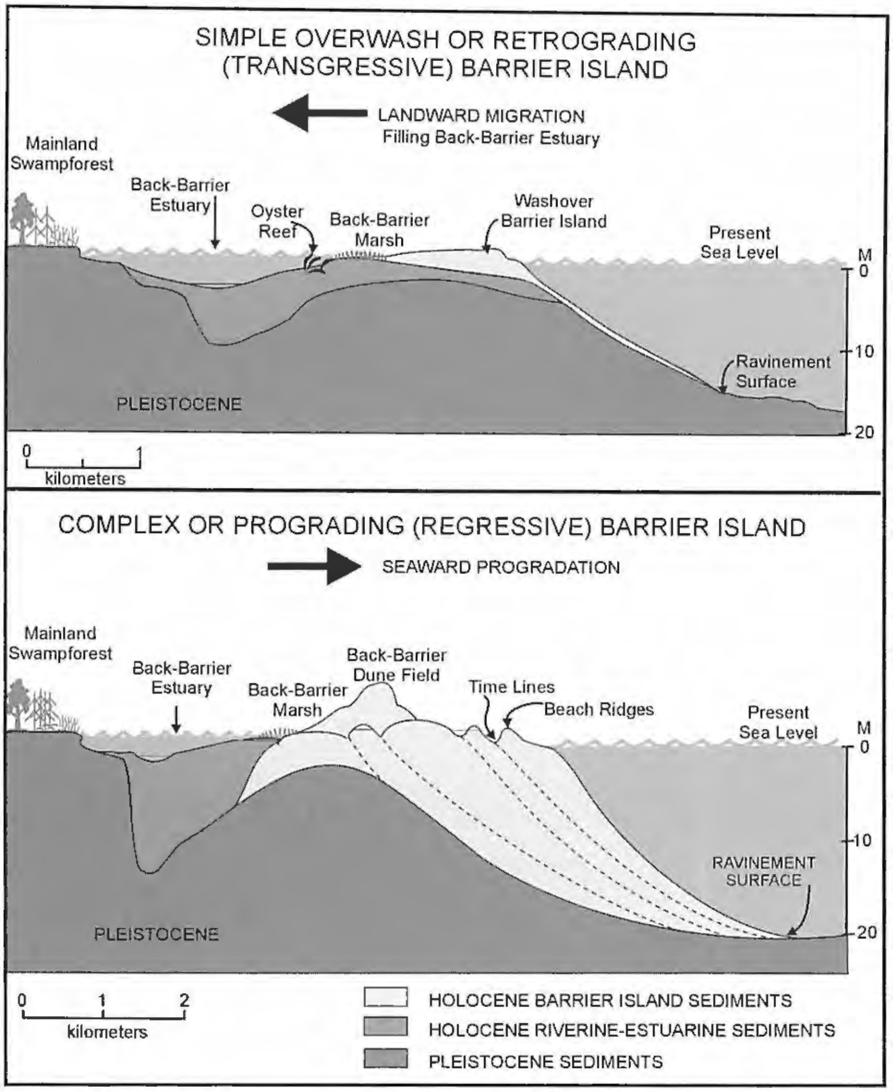


FIGURE 2.13. Schematic cross-sectional diagrams of simple overwash and complex barrier islands and the associated back-barrier estuarine shorelines.

Panel A. Simple overwash barrier islands are dominated by large overwash fans that form during major storm-tide events and produce wide and shallow sand habitats extending well into the back-barrier estuaries. These shallow flats are quickly colonized by fringing marshes that will continue to trap sediment as long as the overwash processes continue unhindered by either natural changes or human development practices, such as building barrier dune ridges, roads and extensive walls of buildings. If the latter happens, then the back-barrier estuarine shoreline may shift from one dominated by constructive processes to one dominated by loss of fringing marsh habitat and net shoreline recession.

Panel B. Complex barrier islands are high and wide with extensive deposits of sand that prevent storm tides from washing over the top of the island. Thus, the back-barrier estuarine shoreline has no direct connection with oceanic processes and results in similar shorelines that characterize the rest of the estuarine system.

sand apron or beach. Sand is often derived from the erosion of adjacent sediment-bank shorelines and transported laterally by longshore currents. Sand can also be derived from the erosion of a particularly sandy unit underlying the shallow perimeter platform. The presence of a sand apron in front of either a swamp-forest or a marsh shoreline will help absorb wave energy and protect the organic shoreline in all but the largest storms.

Back-Barrier Shorelines

Back-barrier estuaries behind sand-starved barrier islands that are dominated by overwash processes are extremely dynamic (Figure 2.13A). They are characterized by extensive modern and ancient overwash fans and old inlet flood-tide deltas extending into the back-barrier estuary. Examples of these types of barrier island shorelines include Masonboro, Figure Eight, Topsail and Madd islands in the southern province and Core Banks and much of the northern Outer Banks, including Ocracoke Island, Buxton Overwash and Pea Island. Sand deposits from overwash and inlet deltas form shallow sand platforms that become important sites for the growth of vast salt marshes and submerged marine grass beds.

In the southern province, the back-

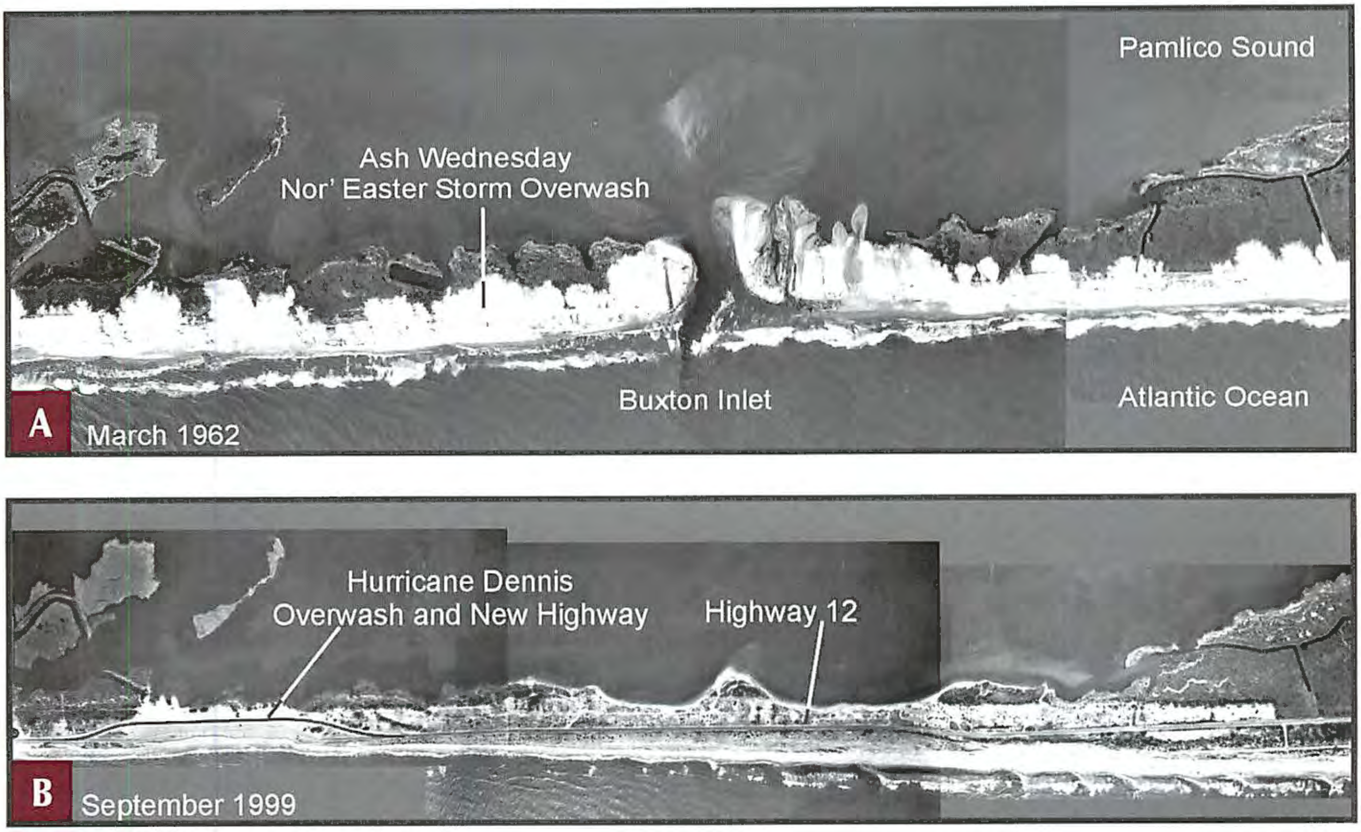


__FIGURE 2.14.__ Comparison of aerial photographs from 3/1962 and 9/1999 for a portion of the Outer Banks between Buxton on the left side to Avon on the right side of the photos. ***Panel A.*** *This aerial photo was taken immediately after the famous Ash Wednesday nor'easter. The simple barrier island segment (Fig. 2.13A) was dominated by overwash processes that dramatically controlled the back-barrier estuarine shoreline by depositing extensive overwash fans over the island and into Pamlico Sound. This process renews the estuarine shoreline and produces broad shallow flats for subsequent growth of marsh and submerged aquatic vegetation that minimizes estuarine shoreline erosion.* ***Panel B.*** *The barrier island segment has been dominated by extensive barrier dune ridges to protect Highway 12 since the 1962 storm. The dune ridges have minimized the overwash process, subjecting the estuarine shoreline to ever-increasing rates of back-barrier shoreline erosion. Today the estuarine shorelines are dominated by eroding salt marsh with local and thin strandplain beaches in coves between the peat headlands. The photo post-dates Hurricane Dennis, a storm that had major impacts upon this coastal region in late August and early September 1999. The photo was taken by the N.C. Department of Transportation to evaluate the condition of coastal Highway 12. Notice that the barrier dune ridge has been severely damaged and was totally eroded away in a few areas, allowing for small overwash fans to develop. However, only in a few areas did overwash cover the roads and in no place did it get back to the estuarine shoreline to naturally renourish the back-barrier beach. Notice how much narrower the island is in 1999 compared to 1962.*

barrier estuaries are dominated by astronomical tides and are so narrow that the back-barrier shoreline rarely erodes. Rather, extensive mud flats accumulate in the low-tide zone along with extensive oyster reefs, while marsh grasses grow in the high-tide zone (Figure 2.12). Minor erosion occurs along the tidal channels that dissect these complex mud-flat and salt-marsh systems, as they slowly migrate through time and in response to changes in inlet and overwash processes. Major erosion does occur along navigational channels wherever they are dredged into the marsh system. However, in general these estuarine shorelines are extremely stable — and actually are accreting.

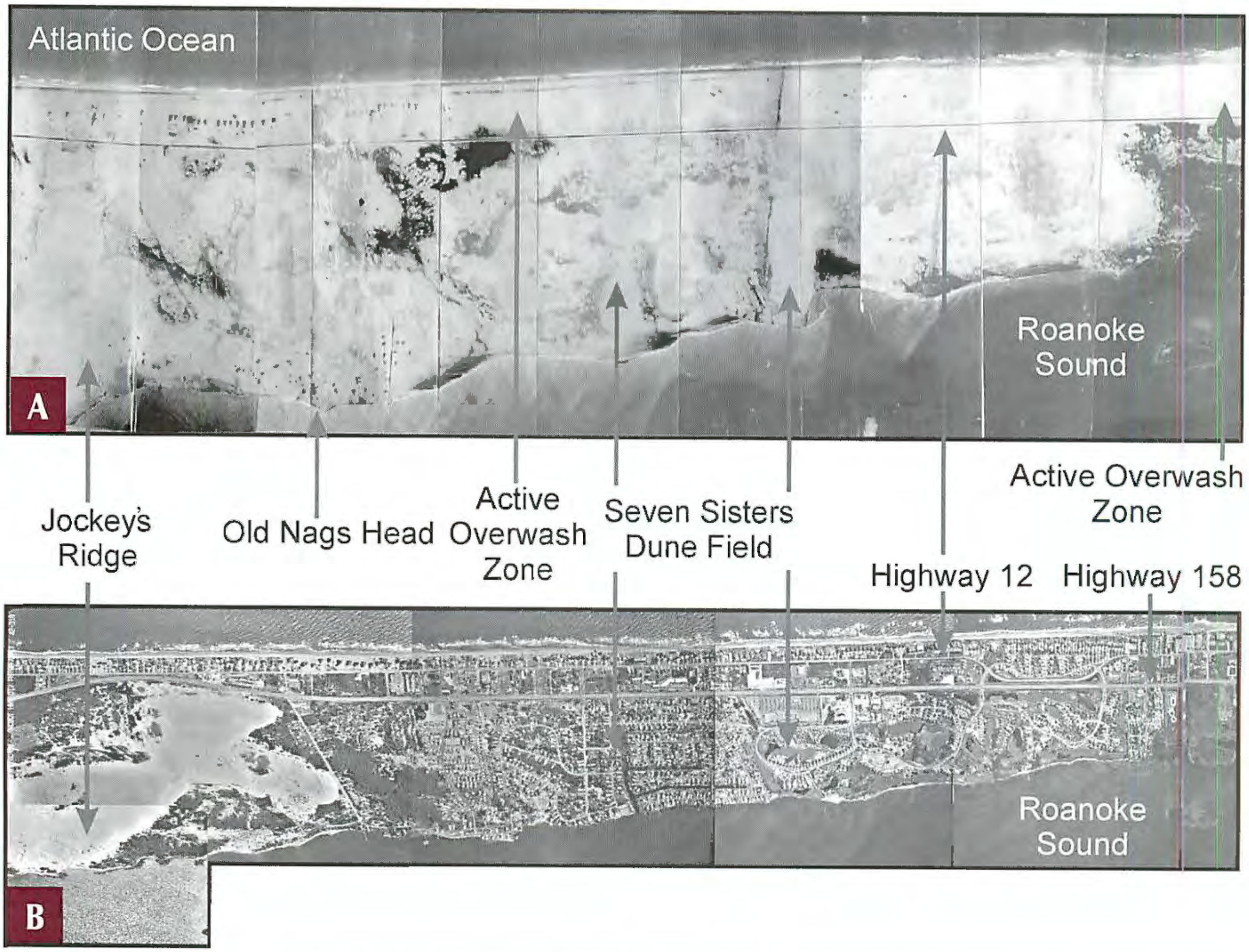


FIGURE 2.15. *Comparison of back-barrier estuarine shorelines on aerial photographs from 10/1932 and 9/1999 for the north portion of Nags Head including Nags Head Woods and Jockey's Ridge and Seven Sisters Dune fields. This segment is a complex barrier island (Fig. 2.13B) that is not dominated by an overwash island. Thus, the back-barrier estuarine shoreline is not under the influence of oceanic processes. Rather, it totally responds to estuarine erosion dynamics similar to the rest of the N.C. estuarine system.* ***Panel A.*** *The aerial photo of this barrier island segment predates any major shoreface modification such as construction of barrier dune ridges that would have inhibited the overwash process. However, Highway 12 had just been constructed, and some of the original Old Nags Head beach houses built in the late 1800s occur on the beach. Notice the village of Old Nags Head on the estuarine side of the island. Jockey's Ridge and Seven Sisters back-barrier dune fields are very extensive. The photos were taken after a major nor'easter in 3/1932 and were done for the Beach Erosion Board (1935) as background data for a beach erosion study.* ***Panel B.*** *This barrier island segment has been dominated by construction and continuous maintenance of extensive barrier dune ridges since the late 1930s, along with a massive amount of development that has minimized frontal overwash process and allowed for the extensive growth of a major vegetative cover. Due to the lack of oceanic processes impacting the back-barrier, the estuarine shoreline is dominated by erosion. Wherever development has occurred, the shoreline has been extensively bulkheaded. However, the area behind Jockey's Ridge still receives some wind-blown sand and thus, has a well- developed sand strandplain beach. The photo was taken by the N.C. Department of Transportation to evaluate shoreline erosion and the condition of Highway 12 following Hurricane Dennis (8-9/1999), which had a major impact upon this coastal segment.*

In the northern province, the back-barrier shorelines associated with the vast Pamlico and Albemarle Sound system are often severely eroding due to the great fetch of these open-water bodies as evidenced by their scarped character. Those shorelines that were dominated by overwash prior to dune-ridge construction in the late 1930s (Figure 2.14A) are in a general state of erosion today as dune ridges were systematically built and rebuilt to prevent the overwash and inlet formation processes. Consequently, there has been little new sand delivered to the backside of the barrier to renew these shorelines (Figure 2.14B). This has resulted in severe rates of shoreline erosion. Similar processes are happening along Core, Roanoke and Currituck sounds, but not so dramatically, due to the smaller size of these water bodies.

Complex barrier islands (Figure 2.13B) are high and wide barrier islands. They include Shackelford and Bogue banks, and Bear and Browns islands in the southern province, and areas near Kitty Hawk, Nags Head (Figure 2.15), Buxton Woods, and the villages of Hatteras and Ocracoke in the northern province. These barrier islands contain large volumes of sand that occur in old beach ridges and back-barrier dune fields. In these situations, oceanic overwash only occurs along the front side of the barrier. Thus, the back-barrier estuarine shoreline is largely independent of oceanic processes and operates in a similar fashion to other mainland estuarine shorelines that respond to estuarine processes as previously described.

The back-barrier estuarine shorelines on complex islands are scarped with wave-cut cliffs and terraces in either older upland sediment units or marsh peat. Strandplain beaches will form if sand is available from either the eroding shoreline, the adjacent shallow estuarine waters, or wind blown off back-barrier dune fields (Figure 2.15). Less well-developed complex islands include the villages of Rodanthe, Waves, Salvo and Avon, which operate similar to mainland estuarine shorelines.

In the northern portion of Nags Head, inlets have never occurred, and overwash has not been an important process. Figure 2.15 shows an extensive and active back-barrier dune field that includes Jockey's Ridge and Seven Sisters. Prior to development in the region, wind processes resulted in the transport of sand onto the back-barrier estuarine shoreline, resulting in extensive sand strandplain beaches that minimized shoreline erosion. However, construction of N.C. Highway 12 in 1932 and the constructed barrier dune ridge in the late 1930s has led to massive dune stabilization with a heavy vegetative cover. Also, large portions of the dunes were extensively mined and leveled for development. These development processes minimized the process of wind-blown sands onto the estuarine shoreline region and resulted in a rapid shift to severe rates of erosion.

Human Modifications to Shoreline Types

With the goal of protecting private property from shoreline erosion, people have tried to stabilize shoreline recession (See *Managing Erosion on Estuarine Shorelines* by Rogers and Skrabal). Construction of any hardened structure designed to stop shoreline recession of sediment-bank shorelines typically reduces or cuts off the sole source of sand for the sand beach. Thus, hardening of property along one shoreline property generally increases the rates of erosion on adjacent properties as their sand supply is reduced. This domino effect may force the neighbors to harden their shoreline, thus accelerating the total rate of beach loss.

If trees and shrubs or their associated debris are removed for the purpose of improving a water view or swimming, the shoreline immediately becomes vulnerable to increased erosion, losing its natural protection. Similarly, fringing marshes provide wave-absorbing functions for shorelines and habitat for estuarine animals.

Construction of permanent structures behind the marsh prevents the natural landward migration of grasses and may eliminate this habitat. Thus hardening and sand traps, such as groins and jetties, change the dynamics of the shoreline as well as the health of the estuarine ecosystems.

Table 2.1 Summary of North Carolina Estuarine Shoreline Erosion Rates

Summary of the average rate of estuarine shoreline erosion for shoreline types in the Albemarle, Pamlico, Neuse and Core-Bogue coastal systems. Data are from Riggs et al. (1978).

SHORELINE TYPES	AVERAGE EROSION RATES (FEET PER YEAR)*
1. Sediment Banks	1.9 to 2.6
A. Low Bank (1-5 Feet)	2.6
B. High Bank (5-20 Feet)	1.9
C. Bluff (Greater Than 20 Feet)	2.1
2. Swamp Forest (Cypress-Gum)	2.1
3. Marsh Grass (Peat Bank)	3.1
Range of All Shorelines**	0.0 to 15.0

* *The erosion rate data are based upon the USDA-SCS (1975) shoreline recession study.*

** *Dependent upon Shoreline Erosion Variables (see next chapter).*

Table 2.2 Summary of North Carolina Estuarine Shoreline Types

Distribution and abundance of shoreline types in the estuarine system of northeastern North Carolina. Data are from Riggs et al. (1978).

STUDY REGION	ALBEMARLE SOUND	PAMLICO RIVER	NEUSE RIVER	CORE-BOGUE SOUNDS	TOTALS
Miles Mapped	436 mi (27%)	483 mi (30%)	452 mi (29%)	222 mi (14%)	1593 mi (100%)
Low — Sediment Bank	159 mi (36%)	112 mi (23%)	124 mi (27%)	76 mi (34%)	471 mi (30%)
High — Sediment Bank	59 mi (14%)	19 mi (4%)	24 mi (5%)	9 mi (4%)	111 mi (7%)
Bluff — Sediment Bank	4 mi (1%)	5 mi (1%)	12 mi (3%)	— —	21 mi (1%)
Swamp Forest	101 mi (23%)	7 mi (2%)	2 mi (<1%)	— —	110 mi (7%)
Marsh	113 mi (26%)	340 mi (70%)	290 mi (64%)	137 mi (62%)	880 mi (55%)

Table 2.3 Summary of Estuarine Shoreline Features by Region

Natural and human features that modify various shoreline types and the erosional and accretionary status of shorelines in the northeastern North Carolina estuarine system. Data are from Riggs et al. (1978).

STUDY REGION	ALBEMARLE SOUND	PAMLICO RIVER	NEUSE RIVER	CORE-BOGUE SOUNDS	TOTALS
Miles Mapped	436 mi (27%)	483 mi (30%)	452 mi (29%)	222 mi (14%)	1593 mi (100%)
Cypress Fringe — Sediment Bank	82 mi (19%)	5 mi (1%)	29 mi (6%)	— —	116 mi (7%)
Marsh Fringe — Sediment Bank	15 mi (3%)	27 mi (6%)	53 mi (12%)	47 mi (21%)	142 mi (9%)
Sand Apron — Marsh	17 mi (4%)	8 mi (2%)	32 mi (7%)	9 mi (4%)	66 mi (4%)
Significant Shoreline Erosion in 1975-1977	390 mi (90%)	457 mi (95%)	408 mi (90%)	200 mi (90%)	1455 mi (91%)
Significant Sand Accretion in 1975-1977	4 mi (1%)	2 mi (<1%)	23 mi (5%)	3 mi (1%)	32 mi (2%)
Human-Modified Shoreline by 1977	41 mi (9%)	24 mi (5%)	20 mi (4%)	19 mi (9%)	104 mi (7%)

Table 2.4 Geologic Framework of North Carolina Provinces

Coastal characteristics of the southern and northern provinces of North Carolina result from differences in the underlying geologic framework. See Figure 2.1 for location of the two provinces.

SOUTHERN PROVINCE	NORTHERN PROVINCE
Cretaceous-Miocene Geologic Framework	Pliocene-Quaternary Geologic Framework
Dominantly rock control	*Dominantly sediment control*
Steep Slopes (avg. = 10 ft/mile)	Gentle Slopes (avg. = 0.5 ft/mile)
Coastal Plain-Draining Rivers (many)	Piedmont-Draining Rivers (4)
Black-water rivers	*Brown-water rivers*
Low sediment input	*High sediment input*
Low freshwater input	*High freshwater input*
Short Barrier Islands — Many Inlets (18)	Long Barrier Islands — few inlets (4)
Maximum astronomical tides/currents	*Minimal astronomical tides*
Maximum saltwater exchange	*Minimal saltwater exchange*
Results: Narrow Back-Barrier Estuaries	Results: Deeply Embayed Estuaries
Regularly flooded	*Irregularly flooded*
Astronomical tide dominated	*Wind-tide and wave dominated*
High-brackish salinities	*Highly variable salinities*

Table 2.5 Shoreline Categories and Parameters

Types of shorelines that characterize the North Carolina estuarine parameters.

SHORELINE CATEGORIES	SUBTYPES	DEFINING PARAMETERS
1. Sediment-Bank Shorelines	Bluff	> 20 feet high
	High Bank	5-20 feet high
	Low Bank	< 5 feet high
2. Organic Shorelines	Swamp Forest	Freshwater riverine floodplains Freshwater pocosins
	Marsh Grass	Fresh, brackish, & salt waters
3. Combination Shorelines	Sediment Bank with Cypress Fringe	
	Sediment Bank with Marsh Fringe	
	Sediment Bank with Fringe of Log and Shrub Debris	
	Low Sediment Bank with Stumps	
	Swamp Forest with Sand Apron	
	Marsh with Sand Apron	
	Human-Modified Shorelines	
4. Back-Barrier Shorelines	Overwash Barriers	Mixed sand fans & salt marshes
	Complex Barriers	Sediment-bank shorelines
	Inlet	Flood-tide deltas

Chapter 3: North Carolina Estuarine Shoreline Erosion Studies

OVERVIEW

Numerous estuarine shoreline erosion studies were previously done for portions of the N.C. coastal counties and include the following: In northeastern North Carolina: Stirewalt and Ingram (1974); USDA-SCS (1975); Dolan and Bosserman (1972); Hardaway (1980); and Everts et al. (1983). Bellis et al. (1975); O'Connor et al. (1978); and Riggs et al. (1978) mapped 1,593 miles of estuarine shorelines in the Albemarle-Pamlico estuarine system.

Also, Hartness and Pearson (1977), summarized the estuarine shoreline erosion in three southern coastal counties: Pender, New Hanover and Brunswick, and established 10 sites in the Pamlico River estuary as long-term erosion control sites.

Locations of these studies are outlined on Figures 3.1 and 3.2. These studies are based upon analyses of old surveys, charts and aerial photos and vary tremendously in scale — from specific small sites around Pamlico Sound to all of the coastal counties, to a portion of the back-barrier estuarine shorelines. However, none were done with the rigor necessary to represent anything other than general patterns of recession and approximate erosion rates. It is interesting to note that in spite of the lack of rigor, they all come up with the same general results and rates of recession. The studies are briefly summarized below.

REGIONAL STUDIES

Pamlico Sound

Using 1938 to 1971 aerial photographs, Stirewalt and Ingram (1974) evaluated the shoreline recession at 16 sites around the perimeter of the Pamlico Sound (Table 3.1, page 38). Five of these sites were situated on the backside of the barrier islands, and 10 sites were on shorelines that rim the mainland coast.

The Stirewalt and Ingram (1974) study made no attempt to relate the changing patterns of shoreline recession to the erosional processes (i.e., shoreline type, fetch, orientation, etc.) nor did they present any methodology concerning their photographic techniques, source of photos utilized or indication of how they arrived at their maximum annual erosion rates. Consequently, I have re-evaluated their maps in an effort to maximize the information concerning erosional processes. Each shoreline segment is divided into a type, including low-sediment bank, swamp forest, and marsh based upon either direct knowledge of the area or aerial photo analysis. These data are only approximations to indicate that shoreline erosion is severe in Pamlico Sound and is ubiquitous throughout all subhabitats (Table 3.2, page 39).

North Carolina Coastal Counties

The USDA-SCS (1975) produced data for 15 coastal counties concerning rates and types of estuarine shoreline erosion (Table 3.3, page 40). Pender, New Hanover and Brunswick counties were judged to have minimal problems with estuarine shoreline erosion, and therefore were not included in their evaluation. Also, erosion processes along the back-barrier estuarine shorelines were considered to be beyond the scope of their study. Table 3.3 (page 40) summarizes the USDA-SCS (1975) shoreline erosion data for 18 coastal counties.

The USDA-SCS study utilized aerial photos from 1938 to 1971 to develop average erosion rates. All of the data were based upon defining a series of reaches within each county that represented areas of similar shoreline types, fetch and land uses. Consequently, all data presented in the study were severely generalized and represent an average number over the distance of each reach (the reaches ranged from 0.5 to 39 miles in length), without any indication of the variability in shoreline type, fetch, land use or erosion rates that occur within the

Facing page: This actively eroding swamp-forest estuarine shoreline is along the south shore of Albemarle Sound.

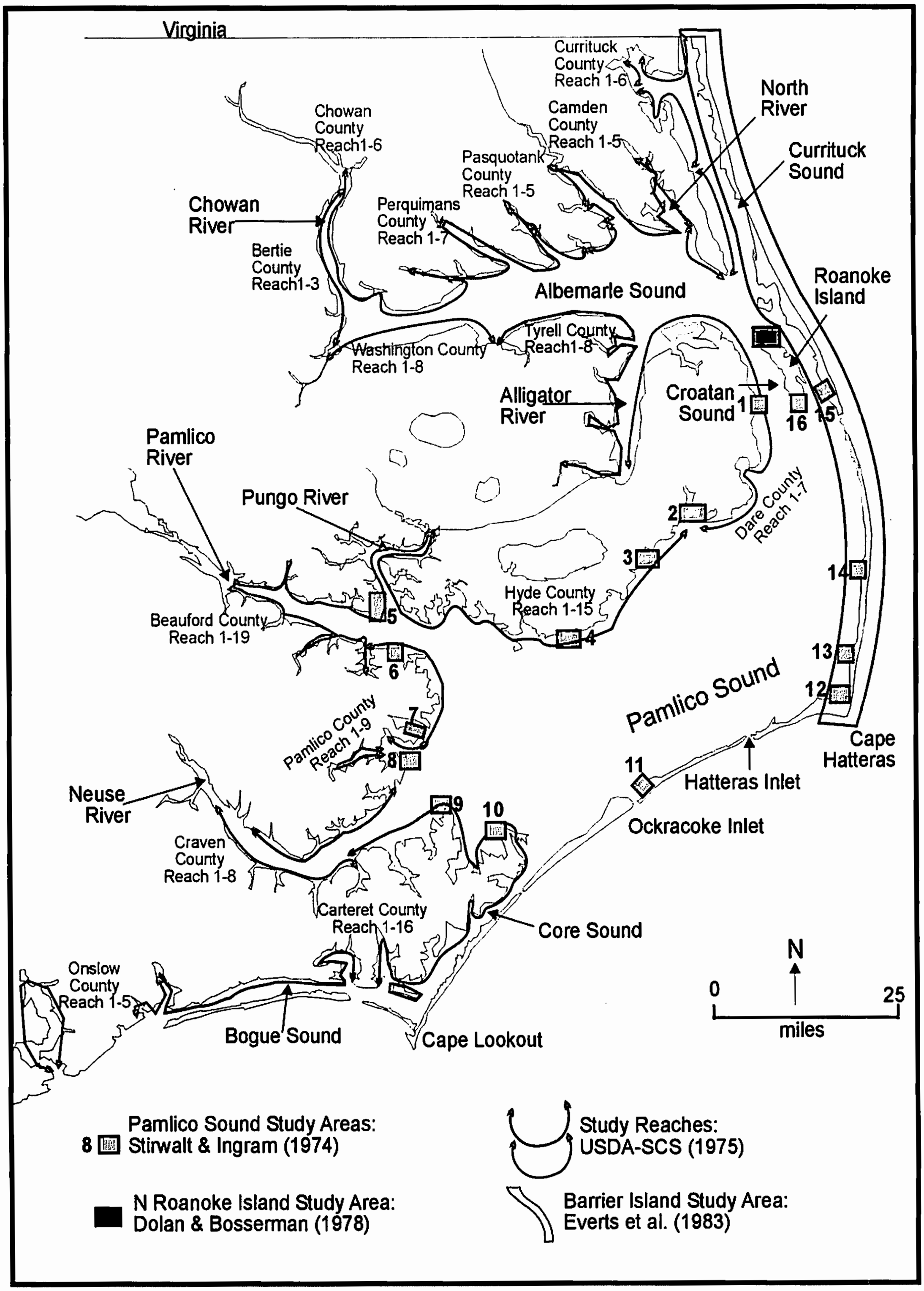


FIGURE 3.1. *Map shows the location of estuarine shoreline erosion studies in the North Carolina coastal system by other researchers.*

reaches. Due to the techniques utilized in this study, the USDA-SCS (1975) shoreline erosion data is extremely general and should not be construed to be exact erosion rates.

Outer Banks Back-Barrier Estuarine Shoreline Erosion

The backsides of barrier islands face estuarine wave conditions, but with less energy than the ocean side. Everts et al. (1983) reviewed shoreline change between 1852 and 1980 for the region from Cape Henry to just west of Cape Hatteras. They concluded that the back-barrier estuarine shorelines were generally in an erosional state. The average retreat rate for the north-south oriented shorelines was 0.33 ft/yr or 33 ft/100 yrs., in contrast to the ocean shoreline, which had an average retreat rate of 2.6 ft/yr. The east-west oriented back-barrier estuarine shorelines (W of Cape Hatteras) eroded at an average rate of 4 ft/yr between about 1850 to 1980, for an average total recession of 530 ft. in 130 years. The Everts et al. report also concluded that the back-barrier estuarine shorelines from Cape Henry to Cape Hatteras increased their net retreat rate between 1850 and 1980, reaching their maximum in the 1949-1980 period, while the Buxton Woods estuarine shoreline west of Cape Hatteras displayed the opposite trend.

Albemarle-Pamlico Estuarine System

Riggs and his colleagues at East Carolina University carried out numerous studies during the 1970s on estuarine shoreline erosion in the N.C. coastal system. These initial studies were done under the auspices of the North Carolina Sea Grant College Program. Locations of these studies are outlined on Figure 3.2. These estuarine shoreline erosion studies consisted of physically mapping the geologic, biologic and hydrologic character of the shorelines on: 1:1000 scale maps from shallow draft boats for all coastal segments included in the study. These data were then combined with an analysis of varions sets of old aerial photographs obtained from the U.S. Department of Agriculture, Soil Conservation Service offices in each coastal county studied. The results were subsequently integrated with the USDA-SCS (1975) study of estuarine shoreline erosion in the N.C. coastal counties.

Tables 2.2 and 2.3 (pages 24 and 25) summarize the distribution and total abundance of shoreline types and the natural and human features that modify various shoreline types, respectively, in northeastern North Carolina. Table 2.1 (page 24) summarizes the average rate of estuarine shoreline erosion for shoreline types within northeastern North Carolina. The following publications resulted from these studies: Bellis, O'Connor, and Riggs (1975); O'Connor, Riggs, and Bellis (1978); Riggs, O'Connor, and Bellis (1978); Hartness and Pearson (1977); and Hardaway (1980).

Centerfold maps for the Albemarle Sound, Pamlico River, Neuse River and Core-Bogue sounds will summarize the distribution of shoreline types for the areas studies. The maps indicate coastal segments that were experiencing significant erosion and portions that were modified and protected by some form of hardened structure at the time of field mapping in 1975-1976. Each shoreline segment is mapped as a specific shoreline type. However, natural complexities and variations of shoreline types occur within each coastal segment. Thus, due to the map scale, only the dominant shoreline type within each coastal segment was mapped.

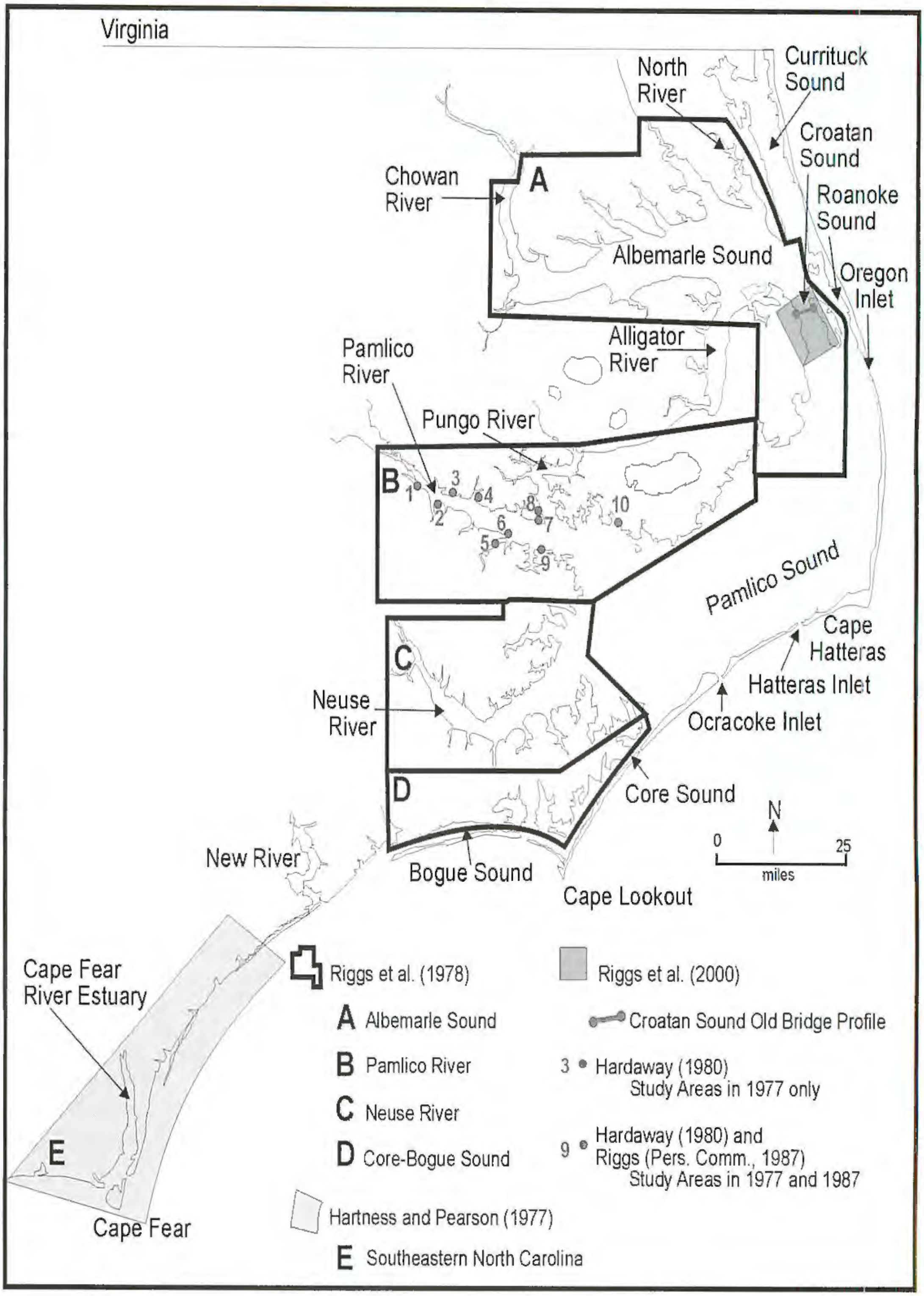
ALBEMARLE SOUND ESTUARINE SYSTEM

Overview

The Albemarle Sound, the northernmost component of the North Carolina estuarine system, features a vast, fresh to low-brackish water complex of creeks, rivers, and open-water sounds (Table 3.4, page 41). Two trunk rivers, the Chowan and the Roanoke, combine to form the Albemarle Sound. Flowing into the Albemarle Sound, from west to east, are the following drowned tributary estuaries: Yeopim, Perquimans, Little, Pasquotank and North rivers on the north side of Albemarle Sound, and the Scuppernong and Alligator rivers on the south side. At the eastern end of Albemarle Sound are three moderately large and open back-barrier estuarine bodies, including Currituck, Croatan and Roanoke sounds. The total shoreline within the system exceeds 500 miles and touches nine counties: Bertie, Camden, Chowan, Currituck, Dare, Pasquotank, Perquimans, Tyrrell and Washington.

Figure 3.3 (centerfold) summarizes the distribution of shoreline types for the Albemarle estuarine system. Sediment banks comprise roughly half of the shorelines in the system, with the remaining half evenly divided between swampforest and marsh. Erosion is ubiquitous and can be locally severe with many areas showing recession far in excess of the average for North Carolina estuaries. This erosion is

FIGURE 3.2. *Map shows the location of estuarine shoreline erosion studies in the North Carolina coastal system by Riggs and his colleagues at East Carolina University.*



due primarily to the general orientation of Albemarle Sound, coupled with large fetches that are commonly more than 50 miles.

Shoreline Descriptions

Table 3.4 (page 41) summarizes the general distribution and abundance of the five dominant shoreline types by county within the mapped portion of the Albemarle Sound estuarine system during 1975-1976. Table 3.5 (page 42) summarizes the distribution and abundance of natural and human features that modify the different types of shorelines, as well as the extent of erosional and accretionary shorelines.

Bluff Shorelines.

Except for the north end of Roanoke Island and parts of Nags Head Woods, bluff shorelines are restricted to the west side of the Chowan River in Bertie County, where the river has eroded into the high Pleistocene terrace that occurs west of the ancient beach ridge known as the Suffolk Scarp. In Bertie County, the lower portions of the bluff sediments commonly consist of compact clay, shelly marl, or iron-cemented sandstone, which effectively reduces erosion by wave undercutting. Such bluffs are characterized with little or no sandy beach.

High-Bank Shorelines.

These shorelines are most common in the western half of the Albemarle Sound system. In Bertie, Chowan, and Perquimans counties, they are the dominant type of sediment-bank shoreline. Erosion rates are typically high, except where compact clays and partially cemented sand sediments comprise the lower portion of the bank.

Low-Bank Shorelines.

Low-bank shorelines are the most abundant type and are dominant within Tyrrell, Pasquotank and Camden counties. Erosion of low-bank shorelines is typically very severe. In most areas, the sediments are unconsolidated and virtually melt when wind tides raise the erosive action of waves up and over the narrow sandy beach and directly attack the low bank. This results in undercutting and slumping of the bank. Longshore and offshore movement of sediment follows, with a rubble of tree and shrub debris being left behind at the shoreline.

Swamp-Forest Shorelines.

Swamp-forest shorelines comprise roughly one-quarter of the shorelines in the Albemarle System and are most extensive in the western regions. Swamp forests occur within the floodplains bordering both the trunk and tributary rivers entering the estuary.

Cypress Fringe and Headland Shorelines.

Many sediment-bank shorelines are characterized by a discontinuous fringe of cypress trees standing in depths of up to 8 feet of water and variable distances from the shore.

Marsh Shorelines.

Marsh comprises about one-fourth of the shoreline in the Albemarle Sound system but is restricted to eastern Camden, Currituck and Dare counties. Black needlerush is the dominant marsh grass and is most extensive in Dare County, where marsh tracts commonly are several miles across.

PAMLICO RIVER AND PAMLICO SOUND ESTUARINE SYSTEM

Overview

The Pamlico River estuarine system is the flooded portion of the Tar River and associated tributary streams. It includes all shorelines in Beaufort and Hyde Counties and the northern portion of Pamlico County to the mouth of Jones Bay (Figure 3.4, centerfold). The Pamlico River extends from its narrow apex at the Tar River mouth just west of Washington, southeastward to the broad expanses of Pamlico Sound. Major components of this estuarine system are the flooded portions of tributary streams, including the Pungo River, South Creek, Goose Creek, Bath Creek, Chocowinity Bay, and numerous smaller tributaries such as Durham and Broad creeks. Figure 3.4 (centerfold) illustrates the distribution of shoreline types throughout the Pamlico River estuarine system.

Shoreline Descriptions

Table 3.6 (page 43) summarizes the general distribution and abundance of the five dominant shoreline types by county within the mapped portion of the Pamlico River estuarine system during 1975-1976. Table 3.7 (page 44) summarizes the distribution and abundance of natural and human features that modify the different types of shorelines, as well as the extent of erosional and accretionary shorelines.

Bluff and High-Bank Shorelines.

Although not widespread, bluffs are the most spectacular of the shorelines found along North Carolina's estuaries. They are all associated with the higher lands that occur west of the Pleistocene Suffolk Scarp along the south side of the Pamlico River. High banks can occur anywhere within the Pamlico River system. However, they are most commonly associated with the region west of the Suffolk Scarp.

Low-Bank Shorelines.

Low banks are by far the most abundant of the sediment-bank shorelines in the Pamlico River system. They are dominant throughout the north shore and east of the Suffolk Scarp on the south shore.

Swamp-Forest Shorelines.

These shorelines occur in the upper headwater portions of Chocowinity Bay and the main Pamlico River estuary west of Washington, where the broad swamp forests of the Tar River floodplain are being drowned. They also occur in the upper freshwater regions of the lateral tributary creeks above the areas included on the map.

Cypress Fringe Shorelines.

A fringe of cypress trees often lines sediment-bank shorelines along the western portion of the Pamlico River and in the upper fresh water portions of the embayed tributaries.

Marsh Shorelines.

The most extensive shoreline type in the Pamlico River system are the marshes. They are most prevalent on low-lying land areas with low- to moderate-saline waters in the eastern portion of the estuarine system. Marshes are particularly dominant in Hyde and Pamlico counties. Abundant growth of marsh grass produces a soft, black, organic peat substrate. The landward extent of these marshes is limited by the height of flooding caused by the irregular wind tides. Due to lower salinities, these marshes are dominated by black needlerush with lesser amounts of several species of cordgrass.

PAMLICO RIVER EROSION MONITOR STATIONS

Overview

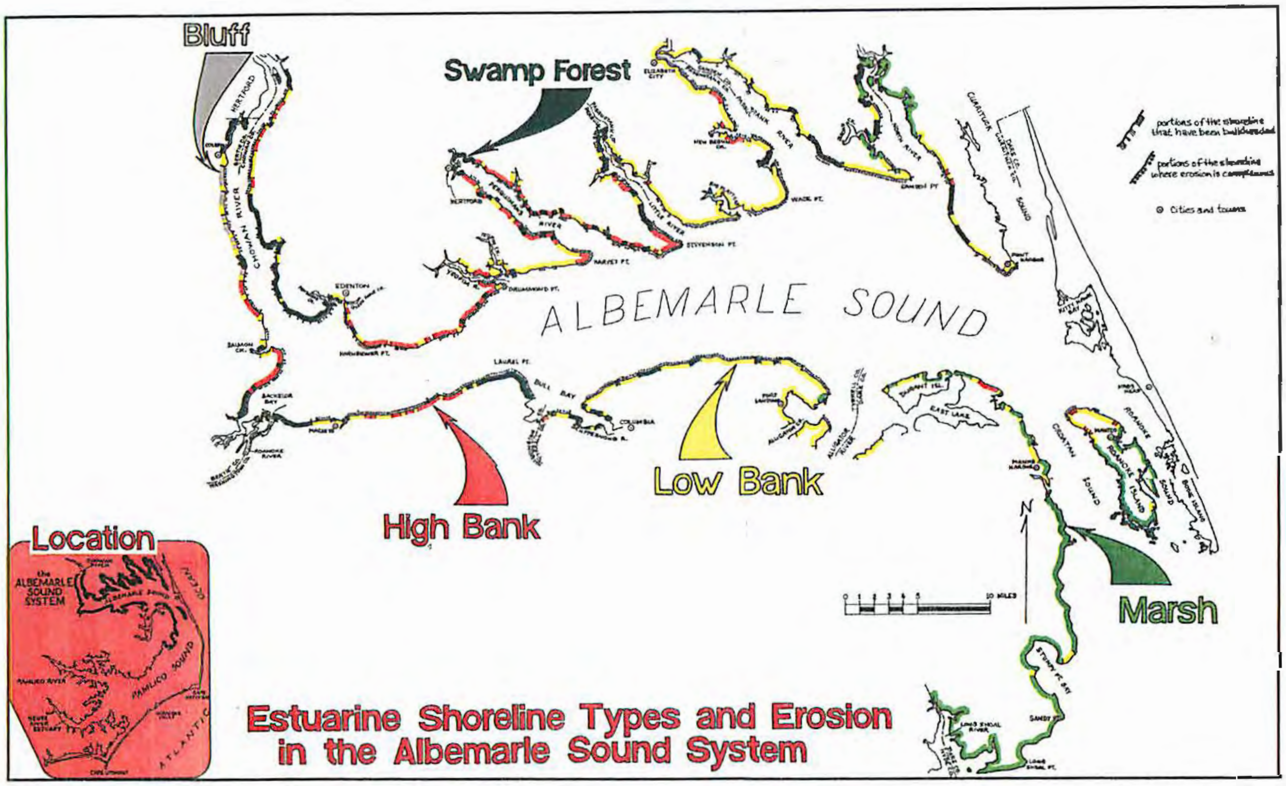
Hardaway (1980) established ten shoreline sites along the Pamlico River estuary (Figure 3.2, page 32). These sites were selected to represent combinations of the three types: sediment-bank, marsh, and human-modified shorelines. In addition, these sites represented different physical variables controlling shoreline erosion, including fetch, geomorphic location, water depth, composition, and abundance of vegetation and land use. Hardaway mapped each site three times over a 16-month period, including August 1977, March 1978 and November 1978. In March 1987, P. Parham (Riggs, pers. comm.) remapped seven of the original Hardaway sites. During the interim, many adjacent land areas were developed, and associated shorelines were often highly modified.

NEUSE RIVER ESTUARINE SYSTEM

Overview

The Neuse River estuarine system extends from Bay River in Pamlico County, south to Cedar Island in Carteret County, and westward to Streets Ferry in Craven County (Figure 3.5, centerfold). The Neuse River originates in the North Carolina piedmont and carries high volumes of fresh water and sediment discharge to the sea. The Neuse River estuary consists of the lower, drowned portion of the river plus numerous smaller, flooded and embayed tributaries. These tributaries originate within the coastal plain. Consequently, they are slow-flowing, black water streams. Major tributaries to the Neuse River estuary include Upper and Lower Broad, Goose, Clubfoot, Adams, Beard, Slocum, Hancock, and Kershaw creeks, and Upper Bay River. Figure 3.5 (centerfold) summarizes the distribution of shoreline types throughout the Neuse River estuarine system.

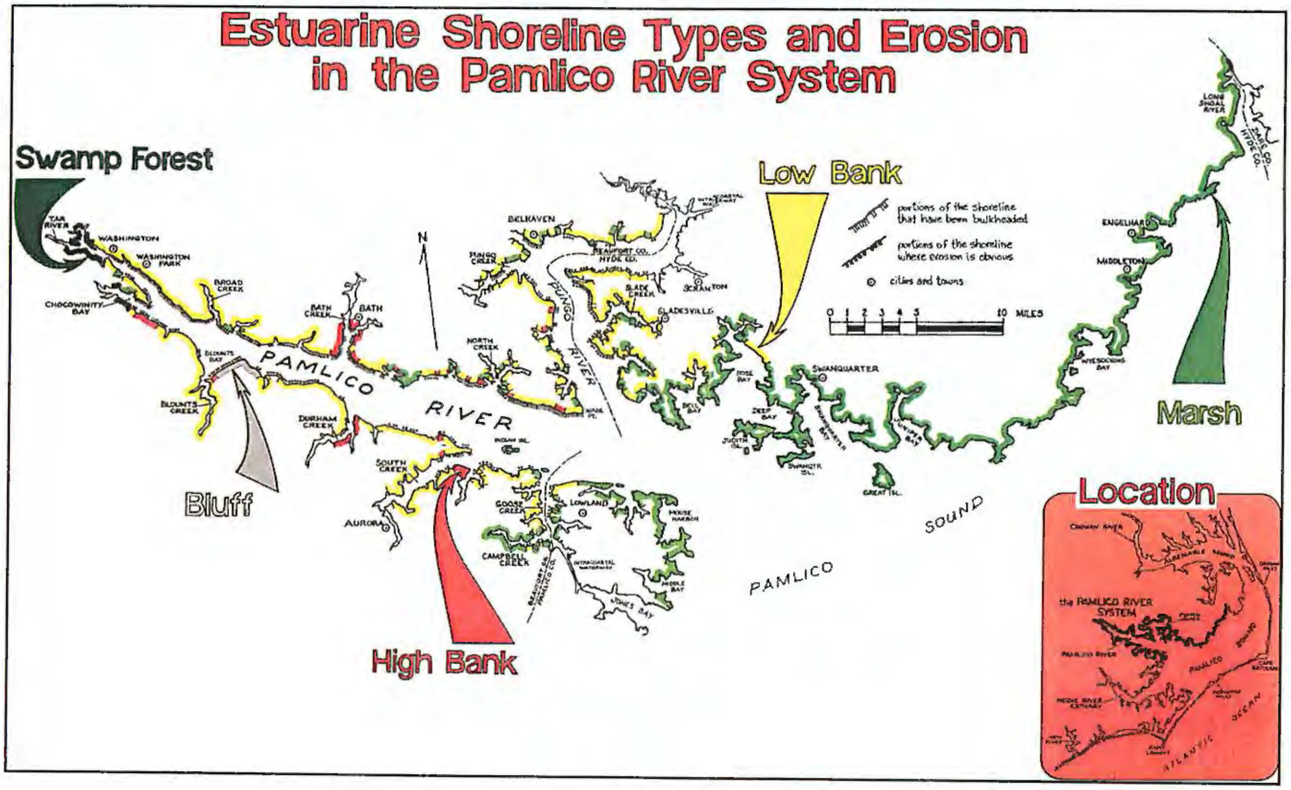
Shoreline erosion within this region is documented at least as far back as 1769 when Royal Gov. Lord Tryon requested the Colonial Assembly to allocate funds to construct bulkheads behind his home, Tryon Palace in New Bern. The assembly denied the request. Shoreline erosion continues to this day and is a major problem throughout the estuarine system. Extensive shoreline erosion is occurring along the grass marshes, but since these marshes have not experienced residential or commercial development, shoreline loss is seldom noticed. All sediment banks are actively eroding. However, this erosion is less conspicuous along the bluffs and high banks on the south side of the river. This is due to the greater volume of sediment eroded from high banks, resulting in slower recession. At Minnesott Beach, the Neuse River intersects an ancient barrier island beach ridge known as the Suffolk Scarp. Erosion of this ancient beach, along with high banks and bluffs, provide an important source of



Estuarine Shoreline Types and Erosion in the Albemarle Sound System

FIGURE 3.3. Distribution of estuarine shoreline types and associated erosion in the Albemarle Sound system of North Carolina. Map is from Riggs et al. (1978). See Tables 3.4 and 3.5 for specific data concerning the regional distribution and abundance of shoreline types and their modification within the Albemarle Sound estuarine system.

FIGURE 3.4. Distribution of estuarine shoreline types and associated erosion in the Pamlico River system of North Carolina. Map is from Riggs et al. (1978). See Tables 3.6, 3.7, and 3.8 for specific data concerning the regional distribution and abundance of shoreline types and their modification within the Pamlico River estuarine system.



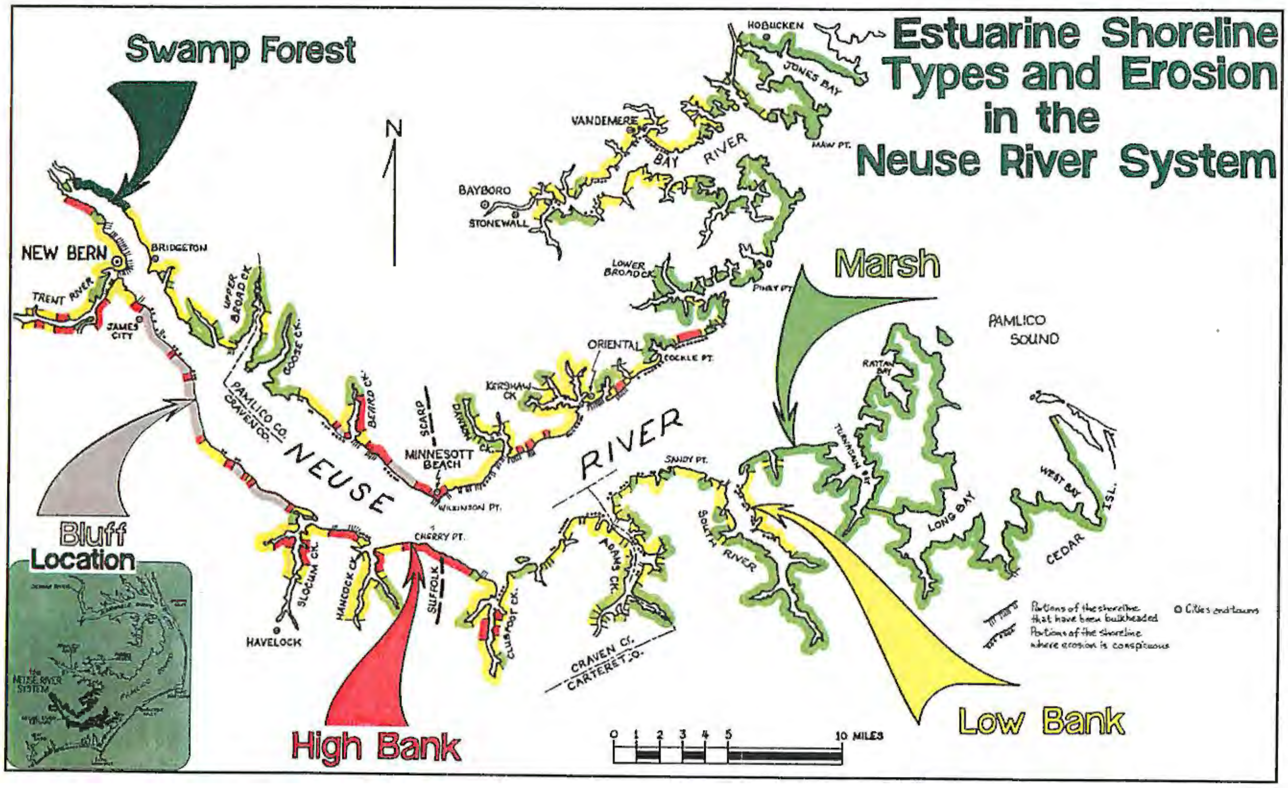


FIGURE 3.5. Distribution of estuarine shoreline types and associated erosion in the Neuse River system of North Carolina. Map is from Riggs et al. (1978). See Tables 3.9 and 3.10 for specific data concerning the regional distribution and abundance of shoreline types and their modification within the Neuse River estuarine system.

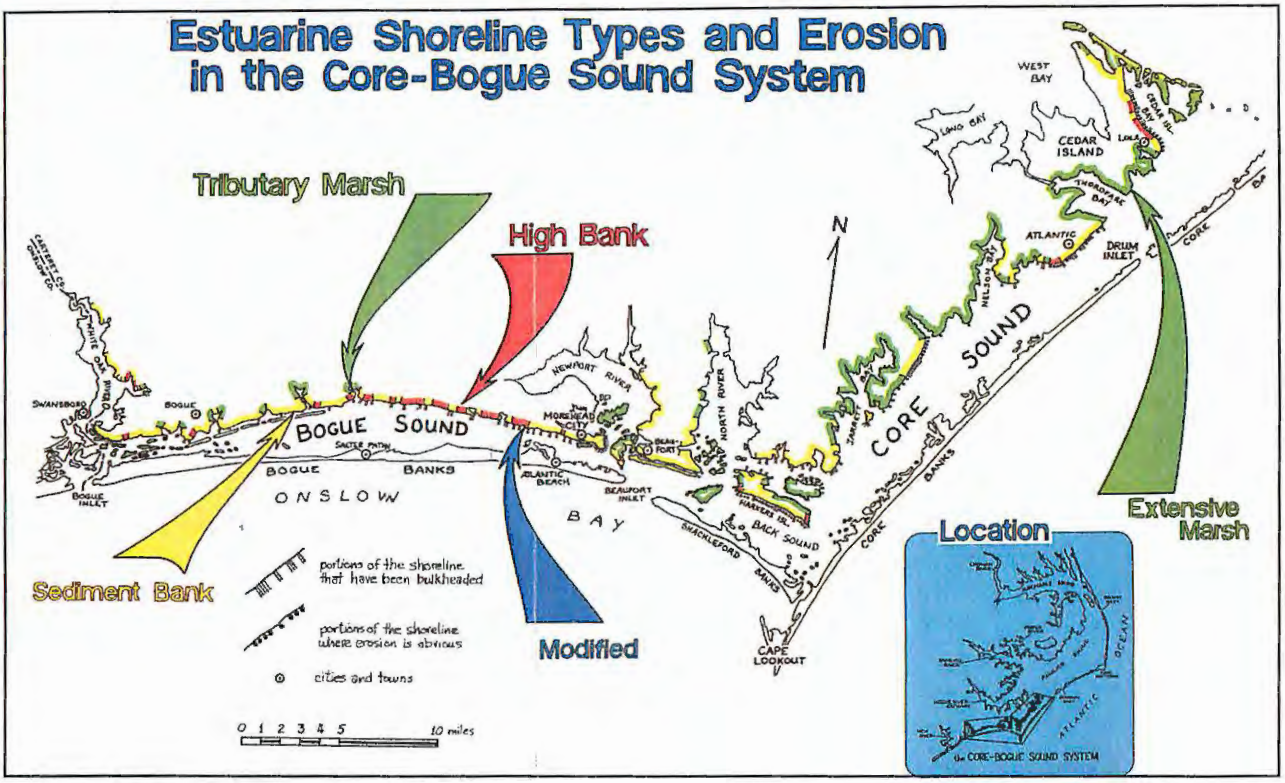


FIGURE 3.6. Distribution of estuarine shoreline types and associated erosion in the Core—Bogue Sound system of North Carolina. Map is from Riggs et al. (1978). See Tables 3.11 and 3.12 for specific data concerning the regional distribution and abundance of shoreline types and their modification within the Core—Bogue Sound estuarine system.

new sands along with estuarine beaches. Because ample sand supplies are available, beach stabilization structures such as groins tend to work more effectively.

Shoreline Descriptions

Table 3.9 (page 46) summarizes the general distribution and abundance of the five dominant shoreline types by county within the mapped portion of the Neuse River estuarine system during 1976-1977. Table 3.10 (page 47) summarizes the distribution and abundance of natural and human features that modify the different types of shorelines, as well as the extent of erosional and accretionary shorelines.

Bluff Shorelines.

Bluffs comprise less than 3 percent of the total shoreline in the Neuse River system. They are restricted to the upper estuary west of the ancient Suffolk Scarp beach ridge that intersects the coast at Minnesott Beach and Cherry Point. A few bluffs occur on either side of Beard Creek and a more extensive line of bluffs runs between James City and Slocum Creek on the south side of the river.

High-Bank Shorelines.

High banks constitute about 5 percent of the shorelines in the Neuse River system and are the dominant type between Slocum and Clubfoot creeks, with a few scattered locations near the town of Oriental and along Bear Creek.

Low-Bank Shorelines.

Low banks are the most abundant of the sediment banks and constitute 28 percent of the shoreline in the system. They contain most of the development within the Neuse River system. Rapid erosion of the low bank occurs as storm waves overstep the narrow, sandy beach and strike against the base of the bank. Since eroding banks contribute relatively small volumes of new sediment to the beach, the sand beaches associated with low banks tend to be narrow or nonexistent.

Marsh Shorelines.

Eastward from Oriental on the north and Adams Creek on the south side of the Neuse River, the shorelines are dominated increasingly by marsh grass. Marsh accounts for 64 percent of the shoreline in the system, most of it occurring within Pamlico and Carteret counties. These marshes are dominated by black needlerush grass with lesser amounts of several species of cordgrass. Organic matter has accumulated for millenia in the more extensive marshes, producing peat beds up to 6 to 10 feet thick on top of the original sandy soil.

Swamp-Forest Shorelines.

Swamp-forest shorelines constitute less than 1 percent of the shorelines and occur on the Neuse and Trent rivers west of New Bern and in the headwaters of tributary estuaries. In the eastern part of the Neuse River system where the estuarine waters become saltier, the cypress and swamp forest are virtually absent except in the uppermost headwaters of the tributary estuaries.

Cypress Headland/ Swamp-Forest Shorelines.

In the western part of the Neuse River system, the low, swampy floodplain of small streams may extend beyond the adjacent sediment-bank shorelines. These narrow zones of cypress extend up to 100 feet out into the Neuse River, producing a point or headland that acts like a large-scale natural groin. The cypress thus form successive points, giving the shoreline a cuspate appearance.

CORE-BOGUE SOUND ESTUARINE SYSTEM

Overview

Figure 3.6 (centerfold) summarizes the distribution of shoreline types along the mainland estuarine shoreline of Core and Bogue sounds, which lies entirely within Carteret County and extends south and west from Cedar Island to the White Oak River. Most lowland areas in the vicinity of Cedar Island contain extensive platform marshes that are irregularly flooded, wind-tide dominated, black needlerush marshes. However, south and west of Atlantic, the Core Sound shoreline is dominated by low clay and sand sediment banks interspersed by tributary embayments. Prominent among these embayments are Nelson and Jarrett bays; North, Newport and White Oak rivers; and Gales, Broad, Goose and Deer creeks. Shorelines along the sounds are dominated by sediment banks with sandy strandplain beaches and narrow fringing marshes of cordgrass. The tributary estuaries are dominated by broad black needlerush marshes.

Because of the narrow and shallow character of these estuarine systems, wave energy tends to be small with extensive marshes that protect many of the sediment-bank shorelines. Consequently, shoreline erosion tends to be low to moderate throughout much of the system. Boat wakes using the Intracoastal

Waterway (ICW) and other major navigation channels are often the most important factor contributing to erosion.

Shoreline Descriptions

Table 3.11 (page 48) summarizes the general distribution and abundance of the five dominant shoreline types in the Core-Bogue Sound estuarine system within Carteret County. Over 65 percent of Carteret County shoreline is in this system. Table 3.12 (page 48) summarizes the distribution and abundance of natural and human features that modify the different types of shorelines, as well as the extent of erosional and accretionary shorelines.

Sediment Bank.

The mainland coast of both Core and Bogue Sounds consists primarily of sediment-bank shorelines. Core Sound is dominated by low sediment banks, whereas Bogue Sound contains both low and high sediment banks. The high-bank shorelines occur wherever the Suffolk Scarp, an ancient beach ridge that occurs along the shoreline, is present and well-developed. When the vegetative cover is lost, the sand-rich Suffolk Scarp erodes, easily causing the bank to readily collapse producing extensive broad and shallow sand beaches. Fortunately, both Core and Bogue sounds are shallow and narrow water bodies with small fetches and wave climates.

Marsh Shorelines.

As either the slope of the land decreases or the degree of protection increases, the narrow fringing marsh expands to become an extensive platform marsh. Platform marshes are most extensive in the eastern portions of Carteret and Pamlico counties and include the marshes of the Cedar Island National Wildlife Refuge in northeastern Carteret County.

Modified Shorelines.

Most mainland shorelines along Bogue Sound consist of sediment banks that have been extensively developed. The natural vegetation has been removed, and the bank graded and seeded along major portions of the shorelines. Since most of the Bogue Sound shoreline has been stabilized, erosion is tied to the success or failure of the modification structures, rather than the natural factors governing erosion and deposition. In addition, the ICW, with its very heavy commercial and pleasure boat traffic, is located close to the shoreline along the northern portion of Bogue Sound. Consequently, boat wakes also can cause significant erosion along certain segments.

ESTUARIES OF THE SOUTHEASTERN COASTAL COUNTIES

Overview

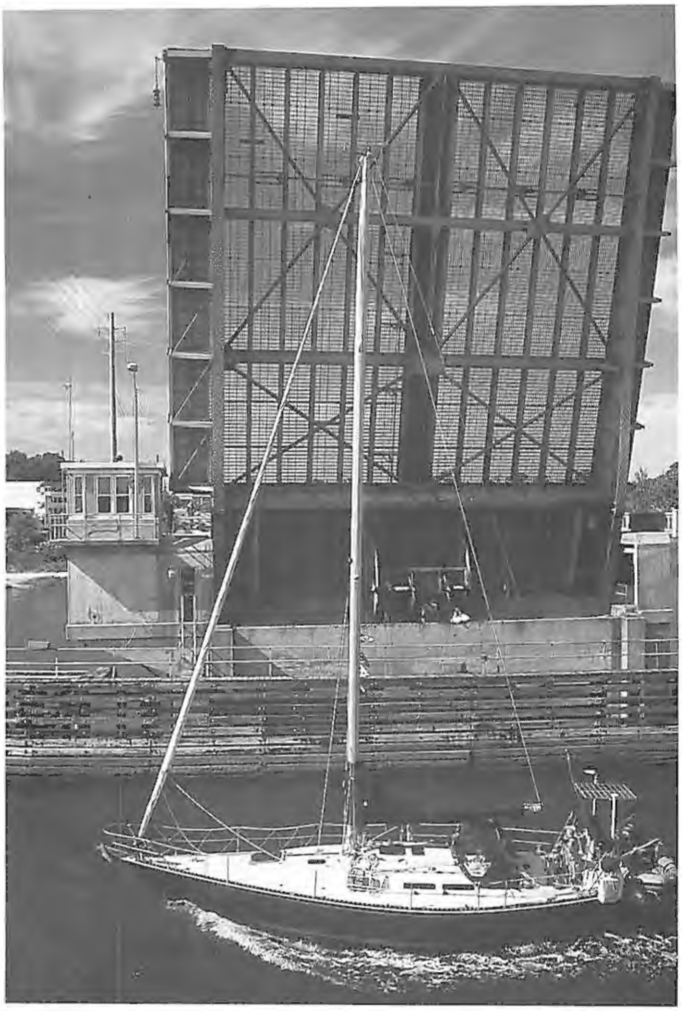
The southeastern counties are characterized by barrier islands with narrow and shallow, shore-parallel sounds. The narrow sounds are largely filled with high-salinity tolerant cordgrass. Extensive shorelines occur within the marsh interior throughout these shallow back-barrier sounds and extend inland along narrow and shallow drowned river estuaries, perpendicular to the sounds. However, construction of the ICW in the 1930s severely modified these sounds.

Table 3.13 (page 49) demonstrates that the dominant shorelines are low sediment banks (22 percent), marsh (24 percent), and the more frequent combination of sediment banks with fringing marshes along the front side (50 percent). The small number of high-bank and bluff shorelines (3.5 percent) occur almost totally along the ICW where it has been dredged across the uplands, such as Snows Cut coming near Carolina Beach in New Hanover County and local portions of Brunswick County. Only 23 percent of the mapped estuarine shorelines are characterized by severe erosional problems. This is largely because of the following characteristics of the shorelines in this portion of the southern coastal province:

- Much of the shoreline is either dominated by salt marsh or contains a salt marsh fringe in front of the sediment bank.
- Most of the 37 miles of eroding shoreline occur along the banks of the ICW and are a direct response to boat wakes.
- The high-bank and bluff shorelines are generally characterized by the most severe rates of shoreline recession due to boat wakes along the ICW.

Shoreline Data

Hartness and Pearson (1977) focused their efforts on the ICW and divided the shore parallel to the coastal system into 12 segments extending from Surf City on Topsail Island to the South Carolina border (Figure 3.2). Table 3.13 summarizes the report data on shoreline types along the 162 miles of shoreline mapped, most of which was along the ICW. Many more miles of estuarine



Major causes of shoreline erosion along the ICW are boat wakes.

shoreline occur within these three counties but were not mapped during this study.

Components of the Hartness and Pearson (1977) study are summarized as follows:

- Significant estuarine shoreline erosion does occur throughout the three southern coastal counties. However, severe erosional processes are restricted to shorelines adjacent to the ICW, other navigational channels, and along the shores of the Cape Fear and New River estuaries.
- Unlike the northeastern estuaries that are dominated by irregular wind tides with only minimal astronomical tidal fluctuation, the southeastern estuaries are dominated by regular astronomical tides and minimal wind tides. The astronomical tidal range varies between 4 to 6 feet in the three counties in this study.
- At high tide, boat wakes are harmlessly baffled within the flooded salt marshes, but overstep the sand beach and severely undercut the adjacent sediment banks. At low tide, boat wakes severely erode the marsh shoreline as the waves impact and undercut the living root mass of the marsh grass, but are dissipated on the sloping beach ramp in front of sediment-bank shorelines.
- The ICW is mostly situated within an artificially dredged channel that has three general occurrences. The channel is dredged in various ways: totally within the tidal marshes that dominate the narrow estuaries, along the western side of the marsh, and adjacent to a sediment-bank shoreline or through an upland region resulting in a narrow channel incised between two sediment-bank shorelines. Most of the high-bank and bluff shorelines occur in the latter situation.
- The major cause of shoreline erosion within the ICW is boat wakes. Fast-moving, deep-draft, pleasure craft can produce up to 4-foot-high wakes that pound the adjacent shorelines. Barge traffic creates a water withdrawal surge that also impacts the shoreline.
- In addition to the other regional variables, the specific rates of erosion along the ICW are directly dependent upon the type and frequency of waterway traffic. Thus, as the amount and size of boat traffic has increased in recent decades, so has the rate of shoreline recession.
- For the first few decades, sediment-bank shorelines along the ICW underwent severe shoreline erosion. However, as the sediment bank was undercut and receded through time, the eroded sediment built a sloping ramp that dampened much of the boat-wake energy during a major portion of the tidal cycle. Thus, shoreline erosion is restricted to the high-tide portion of the tidal cycle, becoming particularly serious during spring and storm tides.
- The Cape Fear and New rivers are drowned river estuaries like those previously described in northeastern North Carolina. Consequently, the shoreline types, processes and rates of shoreline recession are also similar. However, erosion rates are low due to the generally small fetch.

Table 3.1 Pamlico Sound Shoreline Erosion Data

Summary of Stirewalt and Ingram (1974) shoreline erosion data for Pamlico Sound.

STATION NUMBER	COUNTY	LOCATION	PHOTO YRS. TOTAL YRS.	% OF SHORELINE ERODING	MAX. ANNUAL EROSION RATE*
Mainland Shorelines					
1	Dare	Long Wretch Creek	1962-71/9	65%	< 10 ft/yr
2	Dare/Hyde	Long Shoal River	1962-71/9	75%	5 ft/yr
3	Hyde	Gibbs Point	1939-71/32	85%	3.5 ft/yr
4	Hyde	Bluff Point	1945-71/26	90%	> 6 ft/yr
5	Beaufort	Wades Point	1938-71/33	95%	4.5 ft/yr
6	Pamlico	Dick Point	1938-71/33	95%	4.5 ft/yr
7	Pamlico	Sow Island Point	1938-71/33	90%	3 ft/yr
8	Pamlico	Maw Point	1938-71/33	95%	3 ft/yr
9	Carteret	Point of Marsh	1938-71/33	80%	3.5 ft/yr
10	Carteret	Cedar Island	1945-71/26	60%	6 ft/yr
Back-Barrier Shorelines					
11	Hyde	Ocracoke	1945-71/26	90%	11 ft/yr
12	Dare	Buxton	1959-71/12	75%	8 ft/yr
13	Dare	Avon	1945-71/26	95%	7.5 ft/yr
14	Dare	Salvo	1953-71/18	25%	2.5 ft/yr
15	Dare	Bodie Island	1962-71/9	55%	10 ft/yr
16	Dare	Wanchese	1962-71/9	50%	?

** Since the report did not indicate the units, it is assumed that they are in feet/year.*

Table 3.2 Re-Evaluated Pamlico Sound Shoreline Erosion Data

Re-evaluated shoreline erosion data of Stirewalt and Ingram (1974) for the mainland Pamlico Sound study sites.

STATION NUMBER	COUNTY	LOCATION	APPROX. DIRECTION & DISTANCE	TYPE OF SHORELINE	ERODING WATER BODY	PHOTO YRS (TOTAL YRS)	TOTAL RANGE OF RECESSION	MAX. APPROX. ANNUAL EROSION RATE	APPROX. AVE. ANNUAL EROSION RATE
1	Dare	Long Wretch Creek	NE Face/1700 ft	Swamp Forest	N Pamlico Sd	1962-71 (9)	0-400 ft	44 ft/yr	24 ft/yr
			SE Face/3150 ft	Swamp Forest	N Pamlico Sd		0-1400 ft	156 ft/yr	36 ft/yr
2	Dare/Hyde	Long Shoal River	E Face/3500 ft	Marsh/Swamp Forest	Long Shoal River	1962-71 (9)	0-200 ft	22 ft/yr	12 ft/yr
			W Face/2100 ft	Marsh/Swamp Forest	Long Shoal River		0-175 ft	19 ft/yr	6 ft/yr
3	Hyde	Gibbs Point	E & S Face/6600 ft	Marsh	W Pamlico Sd	1939-71 (32)	0-200 ft	6 ft/yr	2 ft/yr
			N Face/5800 ft	Marsh	Farr Creek		0-175 ft	5 ft/yr	1 ft/yr
			E Face/5000 ft	Low Sediment Bank	Farr Creek	1962-71 (9)	0-175 ft	19 ft/yr	7 ft/yr
4	Hyde	Bluff Point	S Face/5800 ft	Marsh	NE Pamlico River	1938-71 (33)	150-1500 ft	45 ft/yr	19 ft/yr
			E Face/1600 ft	Marsh	W Pamlico Sd		0-100 ft	3 ft/yr	2 ft/yr
5	Beaufort	Wades Point	E Face/10300 ft	Low Sediment Bank	SW Pungo River	1938-71 (33)	0-200 ft	6 ft/yr	2 ft/yr
			S Face/6200 ft	Low Sediment Bank	N Pamlico River		0-175 ft	5 ft/yr	2 ft/yr
6	Pamlico	Dick Point	N Face/8600 ft	Marsh	S Pamlico River	1938-71 (33)	25-225 ft	7 ft/yr	4 ft/yr
			S Face/6800 ft	Marsh	Oyster Creek		0-125 ft	4 ft/yr	2 ft/yr
7	Pamlico	Sow Island Point	E Face/3800 ft	Marsh	S Pamlico Sd	1938-71 (33)	50-200 ft	6 ft/yr	3 ft/yr
		Sow Island	N Face	Marsh	S Pamlico Sd		25 ft		1 ft/yr
			E Face	Marsh	S Pamlico Sd		500 ft		15 ft/yr
			S Face	Marsh	S Pamlico Sd		200 ft		6 ft/yr
			W Face	Marsh	S Pamlico Sd		100 ft		3 ft/yr
8	Pamlico	Maw Point	N to E Face/9800 ft	Marsh	NE Neuse River	1938-71 (33)	0-150 ft	5 ft/yr	2 ft/yr
9	Carteret	Point of Marsh	N Face/4400 ft	Marsh	S Pamlico Sd	1938-71 (33)	50-200 ft	6 ft/yr	4 ft/yr
10	Carteret	Cedar Island	N Face/5600 ft	Marsh	S Pamlico Sd	1945-71 (26)	125-200 ft	8 ft/yr	7 ft/yr

Table 3.3 Summary of Shoreline Erosion Data

Summary of shoreline erosion data for 18 coastal counties from the USDA-SCS (1975) study.

COASTAL COUNTY	LENGTH OF SHORELINE STUDIED	PORTION OF SHORELINE ERODING	TIME PERIOD STUDIED*	AVE. BANK HEIGHT	AVE. EROSION RATE
Beaufort	148 mi	85%	32 yrs	3.4 ft	1.7 ft/yr
Bertie	27 mi	73%	32 yrs	15.7 ft	0.9 ft/yr
Camden	39 mi	82%	31 yrs	2.1 ft	2.1 ft/yr
Carteret	179 mi	82%	18 yrs	4.1 ft	2.8 ft/yr
Chowan	42 mi	59%	31 yrs	5.5 ft	0.9 ft/yr
Craven	47 mi	98%	32 yrs	11.5 ft	3.8 ft/yr
Currituck	123 mi	88%	31 yrs	3.4 ft	1.1 ft/yr
Dare	82 mi	98%	22 yrs	1.5 ft	2.0 ft/yr
Hyde	235 mi	100%	25 yrs	0.8 ft	3.0 ft/yr
Onslow	65 mi	40%	15/21 yrs	9.3 ft	1.1 ft/yr
Pamlico	55 mi	99%	32 yrs	5.6 ft	3.5 ft/yr
Pasquotank	29 mi	86%	31 yrs	3.4 ft	2.9 ft/yr
Perquimans	53 mi	84%	31 yrs	5.4 ft	1.7 ft/yr
Tyrrell	90 mi	100%	22 yrs	1.6 ft	2.0 ft/yr
Washington	26 mi	96%	32 yrs	4.5 ft	4.5 ft/yr
TOTALS	**1240 mi**	87%		**5.2 ft**	**2.1 ft/yr**
Brunswick	0 mi	0%			0 ft/yr
New Hanover	0 mi	0%			0 ft/yr
Pender	0 mi	0%			0 ft/yr

* *Based upon available aerial photo coverage ranging from 1949 to 1970.*

Table 3.4 Albemarle Estuarine Shoreline Types

Distribution and abundance of shoreline types in the Albemarle estuarine system, North Carolina. Table is modified from Riggs et al. (1978).

COUNTIES	BERTIE	CAMDEN	CHOWAN	CURRITUCK	DARE	PASQUOTANK	PERQUIMANS	TYRRELL	WASHINGTON	TOTAL MILES
Shoreline Mapped	31.4 mi	46.8 mi	50.8 mi	33.6 mi	104.1 mi	46.2 mi	61.4 mi	40.0 mi	21.4 mi	435.7 mi
Low — Sediment Bank	7.9 (25.2%)	25.4 (54.3%)	8.3 (16.3%)	11.4 (33.9%)	15.3 (14.7%)	35.9 (77.7%)	21.5 (35.0%)	26.8 (67.0%)	6.9 (32.3%)	159.4 (36.6%)
High — Sediment Bank	8.7 (27.7%)	0.0	13.6 (26.8%)	2.0 (6.0%)	2.0 (1.9%)	3.5 (7.6%)	23.5 (38.3%)	0.3 (0.8%)	5.1 (23.8%)	58.7 (13.5%)
Bluff — Sediment Bank	3.5 (11.1%)	0.0	0.3 (0.6%)	0.0	0.2 (0.2%)	0.0	0.0	0.0	0.0	4.0 (0.9%)
Swamp Forest	11.3 (36.0%)	13.2 (28.2%)	28.6 (56.3%)	5.3 (15.8%)	0.0	6.4 (13.9%)	15.3 (24.9%)	11.0 (27.5%)	9.4 (43.9%)	100.5 (23.1%)
Marsh	0.0	8.2 (17.5%)	0.0	14.9 (44.3%)	86.6 (83.2%)	0.4 (0.8%)	1.1 (1.8%)	1.9 (4.7%)	0.0	113.1 (25.9%)

Table 3.5 Albemarle Estuarine Shoreline Features

Natural and human features that modify various shoreline types and the erosional and accretionary status of shorelines in the Albemarle estuarine system, North Carolina. Table is modified from Riggs et al. (1978).

COUNTIES	BERTIE	CAMDEN	CHOWAN	CURRITUCK	DARE	PASQUOTANK	PERQUIMANS	TYRRELL	WASHINGTON	TOTAL MILES
Cypress Fringe — Sediment Bank	12.2 mi (38.9%)	5.6 mi (12.0%)	21.8 mi (42.9%)	1.1 mi (3.3%)	0.2 mi (0.2%)	9.7 mi (21.0%)	20.2 mi (32.9%)	6.1 mi (15.3%)	5.3 mi (24.8%)	82.2 mi (18.9%)
Marsh Fringe — Sediment Bank	0.0 mi	6.6 mi (14.1%)	0.0 mi	1.9 mi (5.7%)	4.3 mi (4.1%)	0.0 mi	0.0 mi	1.9 mi (4.7%)	0.0 mi	14.7 mi (3.4%)
Sand Apron — Marsh	0.0 mi	4.3 mi (9.2%)	0.0 mi	2.0 mi (6.0%)	10.3 mi (9.9%)	0.0 mi	0.0 mi	0.0 mi	0.0 mi	16.6 mi (3.8%)
Significant Shoreline Erosion	28.8 mi (91.8%)	42.1 mi (90.0%)	43.7 mi (86.1%)	28.6 mi (85.1%)	102 mi (98.4%)	33.9 mi (73.4%)	53.0 mi (86.3%)	37.3 mi (93.3%)	19.9 mi (93.0%)	390 mi (89.6%)
Significant Sand Accretion	1.3 mi (4.1%)	0.1 mi (0.2%)	1.4 mi (2.8%)	0.2 mi (0.6%)	0.2 mi (0.2%)	0.0 mi	0.2 mi (0.3%)	0.1 mi (0.3%)	0.6 mi (2.8%)	4.1 mi (0.9%)
Human-Modified Shoreline by 1975	1.3 mi (4.1%)	3.6 mi (7.7%)	5.7 mi (11.2%)	4.8 mi (14.3%)	1.5 mi (1.4%)	12.3 mi (26.6%)	8.2 mi (13.4%)	2.6 mi (6.5%)	0.9 mi (4.2%)	40.9 mi (9.4%)

Table 3.6 Pamlico Estuarine Shoreline Types

Distribution and abundance of shoreline types in the Pamlico River estuarine system, North Carolina. Table is modified from Riggs et al. (1978).

COUNTIES	BEAUFORT (100%)*	HYDE (100%)*	PAMLICO (15.3%)*	TOTALS
Shoreline Mapped	193.6 mi	249.7 mi	40.0 mi	483.3 mi
Low Sediment Bank	82.3 mi (42.5%)	27.5 mi (11.0%)	2.2 mi (5.5%)	112.0 mi (23.2%)
High Sediment Bank	18.5 mi (9.6%)	0.5 mi (0.2%)	0.0 mi	19.0 mi (3.9%)
Bluff Sediment Bank	4.7 mi (2.4%)	0.0 mi	0.0 mi	4.7 mi (1.0%)
Swamp Forest	6.8 mi (3.5%)	0.0 mi	0.0 mi	6.8 mi (1.4%)
Marsh	81.3 mi (42.0%)	221.7 mi (88.8%)	37.8 mi (94.5%)	340.8 mi (70.5%)

* *% of estuarine shoreline in the Pamlico River Estuarine System.*

Table 3.7 Pamlico Estuarine Shoreline Features

Natural and human features that modify various shoreline types and the erosional and accretionary status of shorelines in the Pamlico River estuarine system. Table is modified from Riggs et al. (1978).

COUNTIES	BEAUFORT	HYDE	PAMLICO	TOTALS
Cypress Fringe — Sediment Bank	4.3 mi (2.3%)	0.0 mi	0.0 mi	4.3 mi (0.9%)
Marsh Fringe — Sediment Bank	11.2 mi (6.0%)	15.3 mi (6.1%)	0.0 mi	26.5 mi (5.6%)
Sand Apron — Marsh	0.1 mi (0.05%)	7.7 mi (3.1%)	0.2 mi (0.5%)	8.0 mi (1.7%)
Significant Shoreline Erosion	170.1 mi (87.9%)	247.3 mi (99.0%)	39.5 mi (98.8%)	456.9 mi (94.5%)
Significant Sand Accretion	0.6 mi (0.3%)	1.5 mi (0.6%)	0.0 mi	2.1 mi (0.4%)
Human-Modified Shoreline by 1975	22.9 mi (12.2%)	0.9 mi (0.4%)	0.5 mi (1.3%)	24.3 mi (5.1%)

Table 3.8 Erosion Rates of Pamlico Study Sites

Estuarine shoreline erosion rates of Hardaway (1980) between August 1977 and November 1978 and of Parham (Riggs, person. comm.) between August 1977 and March 1987 for specific shoreline types within the Pamlico River estuary.

SITE	SHORELINE TYPE	HARDAWAY 16-MO. ANNUAL EROSION RATE (FT/YR)	PARHAM 10-YR ANNUAL EROSION RATE (FT/YR)
1.	BAYHILLS:		
	Bluff	1.7	—
	Modified Bluff	0	—
2.	MAULS PT:		
	Bluff	1.7	1.0
	Modified Bluff	0	0
3.	CAMP LEACH:		
	Low Bank/Marsh Fringe	2.3	—
4.	BAYVIEW:		
	High Bank	3.3	2.3
	Low Bank	5.7	2.0
	Marsh	—	1.3
5.	PAMLICO LAB:		
	Low Bank	1.7	2.3
	Modified-Low Bank	—	0
6.	HICKORY PT:		
	Low Bank	4.3	4.3
	Modified-Low Bank	1.7	—
7.	WADE PT-PAMLICO:		
	Marsh	2.7	2.3
	Low Bank	5.0	—
	Modified-Low Bank	0	2.3
8.	WADE PT-PUNGO:		
	Marsh	2.3	1.3
	Low Bank	5.3	1.3
	Modified-Low Bank	—	1.7
9.	LOWLAND:		
	Marsh	2.3	3.0
	Low Bank	5.0	5.0
10.	SWAN QUARTER:		
	Marsh	0.7	—

Table 3.9 Neuse Estuarine Shoreline Types

Distribution and abundance of shoreline types in the Neuse River estuarine system, North Carolina. Table is modified from Riggs et al. (1978).

COUNTIES	CARTERET (34.6%)*	CRAVEN (100%)*	PAMLICO (84.7%)*	TOTALS
Shoreline Mapped	117.2 mi	112.9 mi	221.6 mi	451.7 mi
Low Sediment Bank	23.6 mi (20.1%)	45.7 mi (40.5%)	55.1 mi (24.9%)	124.4 mi (27.5%)
High Sediment Bank	0.5 mi (0.4%)	17.2 mi (15.2%)	5.8 mi (2.6%)	23.5 mi (5.2%)
Bluff Sediment Bank	0.0 mi	9.7 mi (8.6%)	1.9 mi (0.9%)	11.6 mi (2.5%)
Swamp Forest	0.0 mi	2.2 mi (1.9%)	0.0 mi	2.2 mi (0.5%)
Marsh	93.1 mi (79.5%)	38.1 mi (33.8%)	158.8 mi (71.6%)	290.0 mi (64.3%)

* *% of estuarine shoreline in the Neuse River Estuarine System.*

Table 3.10 Neuse Estuarine Shoreline Features

Natural and human features that modify various shoreline types and the erosional and accretionary status of shorelines in the Neuse River estuarine system. Table is modified from Riggs et al. (1978).

COUNTIES	CARTERET	CRAVEN	PAMLICO	TOTALS
Cypress Fringe — Sediment Bank	0.5 mi (0.4%)	21.7 mi (19.2%)	6.9 mi (3.1%)	29.1 mi (6.4%)
Marsh Fringe — Sediment Bank	18.3 mi (15.6%)	25.9 mi (23.0%)	8.9 mi (4.0%)	53.1 (11.8%)
Sand Apron — Marsh	21.1 m (18.0%)	6.8 mi (6.0%)	4.5 mi (2.0%)	32.4 mi (7.2%)
Significant Shoreline Erosion	5.1 mi (4.4%)	8.9 mi (7.9%)	23.1 mi (9.6%)	407.7 mi (90.3%)
Significant Sand Accretion	8.1 mi (6.9%)	25.9 mi (8.6%)	5.3 mi (2.4%)	23.1 mi (5.1%)
Human-Modified Shoreline by 1976	1.4 mi (1.2%)	9.6 mi (8.5%)	9.9 mi (4.5%)	20.9 mi (4.6%)

Table 3.11 Core-Bogue Estuarine Shoreline Types

Distribution and abundance of shoreline types in Core-Bogue Sound estuarine system, North Carolina. Table is modified from Riggs et al. (1978).

SHORELINE TYPE	CARTERET COUNTY
Shoreline Mapped	222.0 mi*
Low Sediment Bank	76.3 mi (34.4%)
High Sediment Bank	9.2 mi (4.1%)
Marsh	136.5 mi (61.5%)

** 65.4% of Carteret County shoreline is in Core-Bogue Sound estuarine system.*

Table 3.12 Core-Bogue Estuarine Shoreline Features

Natural and human features that modify various shoreline types and the erosional and accretionary status of shorelines in the Core-Bogue Sound estuarine system. Table is modified from Riggs et al. (1978).

SHORELINE TYPE	CARTERET COUNTY
Marsh Fringe — Sediment Bank	46.6 mi (21.0%)*
Sand Apron — Marsh	9.2 mi (4.1%)
Significant Shoreline Erosion	200.4 mi (90.2%)
Significant Sand Accretion	2.7 mi (1.2%)
Human-Modified Shoreline by 1976	18.9 mi (8.5%)

** 65.4% of Carteret County shoreline is in Core-Bogue Sound estuarine system.*

Table 3.13 Southeastern N.C. Estuarine Shoreline Types

Distribution and abundance of shoreline types along the banks of the Intracoastal Waterway in southeastern North Carolina. Data are summarized from Hartness and Pearson (1977).

COUNTIES	PENDER	NEW HANOVER	BRUNSWICK	TOTALS
Shoreline Mapped	41.2 mi (25.4%)	50.2 mi (31.0%)	70.6 (43.6%)	162.0 mi
Low Sediment Bank	8.8 mi (5.4%)	9.3 mi (5.7%)	17.5 mi (10.8%)	35.6 mi (22.0%)
High Sediment Bank	0.8 mi (0.5%)	2.5 mi (1.5%)	1.8 mi (1.1%)	5.1 mi (3.1%)
Bluff Sediment Bank	0 mi	0 mi	0.7 mi (0.4%)	0.7 mi (0.4%)
Marsh	12.4 mi	11.4 mi (1.9%)	15.6 mi	(0.5%)
Marsh Fringe with Sediment Bank	19.2 mi (11.9%)	27.0 mi (16.7%)	35.0 mi (21.6%)	81.2 mi (50.1%)
Mapped Shoreline Experiencing Significant Erosion	5.0 mi (3.1%)	11.0 mi (6.8%)	21.5 mi (13.3%)	37.5 mi (23.2%)

Chapter 4: Estimating Relative Estuarine Shoreline Erosion Potential

INTRODUCTION TO EVALUATION SYSTEM

In 1978, under the auspices of the North Carolina Sea Grant College Program, O'Connor et al. produced the following "do it yourself" estuarine shoreline erosion evaluation system. This system (Table 4.1) was designed as a method for planners, landowners, and prospective buyers of estuarine shoreline property to obtain a relative indication of the intensity of erosion along any specific shoreline segment and to aid in understanding the basic processes associated with ongoing problems of coastal property loss. The 12 major shoreline variables **(I)** that control erosion are listed along the left side of Table 4.1. Each variable is divided into a number of descriptive categories **(II)**, and each category has an assigned erosion potential value, or **EPV (III)**.

It is imperative to remember that the rate and amount of shoreline erosion in any specific location is quite variable from year to year. Shoreline erosion is generally a direct product of high-energy storms, and consequently, the rate and amount of erosion depends upon the following:

- storm frequency;
- storm type and direction;
- storm intensity and duration; and
- resulting wind tides, currents and waves.

Also, the presence of human-made structures (bulkheads, groins, etc.) significantly modifies the erosion potential, increasing or decreasing it to a degree depending on the type, location, and design of the structure on the specific property, as well as on adjacent properties.

But once erosion rates are predicted, land management options can be considered (see Rogers & Skrabal) in light of overall protection and estuarine water quality.

INSTRUCTIONS FOR USE

To write your evaluation, make a copy of Part I and Part II. The evaluation can be done most readily while standing on the shoreline of the specific property of interest. It also is helpful to have several different maps and vegetation guidebooks for reference while making the CPEV determination. Helpful maps might include the following, and should be available at a local map store:

- U.S. Geological Survey 1:100,000 or 1:250,000 scale, topographic maps to provide regional information on geographic setting and fetch.
- U.S. Geological Survey 1:24,000 scale, topographic quadrangle map to provide detailed information on specified lands.
- U.S. Coast and Geodetic Survey chart that shows the bathymetry and location of navigational channels.

In addition, aerial photos can be very helpful in evaluating both the vegetation and history of shoreline erosion for a given property. Aerial photos, often dating back to 1938 or 1940, can generally be observed for one or more time periods. They can be found at the local offices of the county cooperative extension agent, or the N.C. Division of Coastal Management.

Facing page: A classic "going-to-sea" highway at Wades Point is at the confluence of the Pungo and Pamlico rivers.

PART I

Determine the Cumulative Erosion Potential Value (CEPV)

Using Table 4.1 (pages 53 and 54), to determine the **CPEV** by going through the following steps:

1. Systemically consider each of the 12 shoreline variables **(I)** and match the characteristics of the segment of estuarine shoreline under consideration to the appropriate description **(II)** to the right of each variable.

2. Place the **EPV** assigned to the appropriate description **(II)** for each of the 12 shoreline variables in the right-hand column **(III)**. If you estimation of a variable falls within two descriptive categories, record the higher of the two **EPVs**.

3. Obtain the cumulative erosion potential value or **CEPV (IV)** by adding the assigned **EPVs** recorded in column **III**.

4. Compare the **CEPV (IV)** obtained for the segment of shoreline under consideration with the shoreline erosion potential scale **(V)**.

PART II

Determine the Erosion Potential (EP)

To estimate the shoreline erosion potential **(EP)** and possible erosion rate for any given property, plug the cumulative erosion potential value **(CEPV)** as determined from Part I into Part II. This provides an approximation of what might be expected along a given segment of estuarine shoreline.

Landowners can measure shoreline erosion by determining the CPEV and EP.

Table 4.1 Weighing Variables for Shoreline Prediction

The shoreline variables that determine the Cumulative Erosion Potential Value (CEPV) for any specific estuarine coastal segment. Table is Modified from O'Connor et al. (1978). See text for instructions.

I. SHORELINE VARIABLES	II. DESCRIPTIVE CATEGORIES *Erosion Potential Values (EPV) are the Upper Row of Numbers*							III. TOTAL EPV
1. Fetch	**0**	**2**	**4**	**6**	**8**	**10**	**12**	
Avg. Distance (miles) of Open Water Measured 45° Either Side of the Perpendicular to Shoreline	< 1/10	1/10 to 1/3	1/3 to 1	1 to 3	3 to 10	10 to 30	> 30	
2. Water Depth at 20 Feet	**1**	**2**	**3**	**5**	**6**			
From Shoreline (in feet; measured at mean high water)	< 1	1 to 3	3 to 6	6 to 12	> 12			
3. Water Depth at 100 Feet	**1**	**2**	**3**	**5**	**6**			
From Shoreline (in feet; measured at mean high water)	< 1	1 to 3	3 to 6	6 to 12	> 12			
4. Bank Height	**1**	**2**	**3**	**5**	**6**			
at the Shoreline or Immediately Behind Sediment Beach (in feet)	> 20	20 to 10	10 to 5	5 to 1	< 1			
5. Bank Composition	**0**		**8**		**16**			
and Degree of Sediment Induration	Rock, Marl, Tight Clay, Well-Cemented Sand (break with hammer or dig with pick) or Swamp Forest		Soft Clay, Clayey Sand, Moderately Cemented Sand (easily dug with knife)		Uncemented Sands, or Peat (easily dug with hand)			
6. Sand Beach Width	**0**	**1**	**2**	**3**	**5**	**6**		
Between Bank and Shoreline (in feet; measured at mean high water)	Swamp Forest (no beach) or Less Than 1/3 Mile Fetch	> 20	20 to 10	10 to 5	5 to 1	< 1, or Broad Marsh		

Continued on the next page

Table 4.1 Weighing Variables for Shoreline Prediction, continued

I. SHORELINE VARIABLES	II. DESCRIPTIVE CATEGORIES *Erosion Potential Values (EPV) are the Upper Row of Numbers*				III. TOTAL EPV
7. Offshore Vegetation Type and Abundance of Vegetation Occurring in the Water Off the Shoreline	**1** Dense or Abundant Cypress and/or Aquatic Grasses (submerged weed beds)	**4** Scattered or Patchy Vegetation; Marsh Grass, Cypress, and/or Upland Trees and Shrubs	**6** Lack of Cypress and/or Aquatic Grasses (submerged weed beds)		
8. Shore Vegetation Type and Abundance of Vegetation Occurring on a Sand Beach Between the Bank and Shoreline	**0** No Sediment Beach	**1** Dense Continuous Vegetation; Marsh Fringe, Cypress Fringe, and/or Upland Trees/Shrubs	**4** Scattered or Patchy Vegetation; Marsh Grass, Cypress and/or Upland Trees and Shrubs	**8** Lack of Living Vegetation; Abundant Stumps and Logs in Water; or a Marsh with No Sand Beach	
9. Bank Vegetation Type and Abundance of Vegetation Occurring on the Bank and Immediately on Top of Bank Lip	**1** Dense Vegetation; Upland Trees and Shrubs, Grass	**4** Clumps of Vegetation Alternating with Areas Lacking Vegetation	**6** Lack of Vegetation (cleared), Annual Plants (crop or agricultural land), or Extensive Marsh		
10. Shoreline Geometry General Shape of Shoreline at the Point of Interest Plus 200 Yards on Either Side	**1** Coves	**4** Irregular Shoreline	**8** Headland or Straight Shoreline		
11. Shoreline Orientation General Geographic Direction the Shoreline Faces	**0** < 1/3 Mile Fetch	**1** South to East	**3** South to West	**4** West to North to East	
12. Boat Wakes Proximity to and use of Boat Channels	**1** No Channels within 100 Yards, Broad Open Water Body, or Constricted Shallow Water Body	**8** Minor Channel within 100 Yards Carrying Limited Traffic, or Major Channel 100 Yards to .5 mile Offshore	**16** Major Channel within 100 Yards; Particularly the Intracoastal Waterway		
IV. CUMULATIVE EROSION POTENTIAL VALUE (CEPV) =					

Table 4.2 Determining Shoreline Erosion Potential

Estimation of the shoreline erosion potential (EP) and possible erosion rates based upon the cumulative erosion potential value (CEPV) as determined from Table 4.1

IV. CEPV VALUE	ESTIMATED EROSION RATE	V. EROSION POTENTIAL (EP)
0 to 33	Low	< 3 Ft/Yr
34 to 66	Intermediate	3 to 6 Ft/Yr
67 to 100	High	> 6 Ft/Yr

Chapter 5: Four Basic Concepts Concerning Estuarine Shoreline Erosion

ESTUARINE SHORELINES ARE ERODING

The history of the North Carolina coastal plain and present coastal system consist of traumatic and constant change. This evolutionary change continues today as it has throughout our past. Ongoing sea-level rise has drowned the highly irregular drainage basin topography of the Coastal Plain, producing about 4,000 miles of estuarine shoreline. About 3,000 miles of these shorelines occur within the vast Albemarle-Pamlico-Core-Bogue Sound systems of northeastern North Carolina and are generally all in a state of shoreline recession.

Most of the estuarine shorelines south of Bogue Sound are extremely narrow, shallow, and filled with salt marshes and associated mud flats. These shorelines are generally not eroding as the marshes and flats vertically accrete sediment to keep up with rising sea level. Within this region, shoreline erosion is severe only within the drowned-river estuaries such as the Cape Fear, New, and White Oak rivers and along the Intracoastal Waterway (ICW) and associated navigational channels.

Table 1.1 (page 4) estimates the land loss that has occurred over the past 25 years based upon the data of the USDA (1975) and Riggs et al. (1978). If today's rate of estuarine shoreline recession in response to ongoing sea-level rise continues into the future, the total land loss for coastal North Carolina could be extremely significant.

SHORELINE EROSION VARIABLES

The absolute amount and rate of erosion along any specific shoreline segment are directly dependent upon major shoreline variables. These variables are defined in Table 4.1 (pages 53 and 54) and include the physical setting, exposure to storm energy, shoreline composition, water depth, presence of vegetation, and boat wakes.

Physical Factors

The physical setting of each shoreline segment determines its exposure to high-energy waves and storm tides that erode sediment banks, destroy vegetation and set up longshore currents. Geographic location, geometry of the shoreline, and offshore bottom characteristics are one set of factors that determine wave height and storm surge. Height and composition of the sediment banks are other key physical factors controlling shoreline erosion.

Fringing Vegetation

Natural vegetation often forms the most effective protection from erosion. Vegetation along the shoreline may occur as zones of trees and shrubs, fringes of marsh grass, or tangles of dead brush, logs and stumps. Zones of vegetation in the nearshore water or on the beach effectively absorb wave energy during storm events, slow down rates of shoreline recession, and act as natural bulkheads and groins that trap and hold sand. Cutting, clearing and removing trees, shrubs, stumps, logs, and snags changes the shallow-water habitats and always increases the rates of shoreline erosion.

Submerged aquatic vegetation (SAV) commonly grows in the bottom shallow waters in front of sediment-bank shorelines. SAV effectively dampens wave energy as waves move through shallow water towards the strandplain beach. Marsh platforms and fringing marshes in front of sediment-bank

Facing page: An actively eroding high sediment-bank shoreline with a broad strandplain beach is along the Neuse River estuary.

shorelines generally act as very effective energy baffles during high-storm tide conditions. During storm tides, marsh grasses are capable of baffling much of the wave energy in all except the highest storm tidal situations. Thus, little wave energy gets to the sediment bank behind the marsh habitats.

Effect of Boats

Shorelines adjacent to navigational channels that carry significant boat traffic are characterized by high rates of shoreline erosion. This is particularly true of the ICW and other deep channels that carry commercial traffic, as well as high-powered recreational boaters. These vessels displace large volumes of water and create large wakes that repeatedly break on the adjacent sediment bank, marsh or swamp-forest shorelines.

The booming boating industry parallels the growth in development and tourism. Vessels in shallow, coastal waters generally require a system of navigational channels and marinas, which means dredging initial channels, followed by regular maintenance dredging. Channel dredging and spoils disposal significantly alter the morphology of the shallow-water habitats that affect the water circulation system, benthic habitats, and marsh hydrology. The increasing economic role of the boat and shipping industry within estuarine waters is resulting in the ever-increasing role of boat wakes as an important process in estuarine shoreline erosion.

STORMS AND STORM TIDES

Causes of Estuarine Storm Tides

Dramatic shoreline erosion does not occur on a day-to-day basis, but rather is a direct product of high-energy storm events. Consequently, in any specific location, erosion is a process that is extremely variable from year to year and depends upon climatic conditions, such as storm frequency, type, direction, intensity and resulting storm tides, waves and currents.

Estuaries within the northern province tend to be large, open bodies of water with minimal astronomical tidal fluctuation and dominated by irregular wind and storm tides. With a large water area over which the storm winds can blow (fetch) and shallow depth, high-energy, storm-related waves and currents develop, which can move considerable sediment during any one event. This leads to serious, acute erosion problems.

Estuarine storm tides happen whenever storms impact the coast. The resulting storm tide depends upon the intensity, duration and direction of movement of each storm. Frontal storms (i.e., nor'easters) are characterized by winds that range from 25 to 50 mph, whereas tropical depressions and hurricanes will typically come ashore with winds in considerable excess of this. Consequently, frontal storm tides generally range from 2 to 5 feet above MSL (mean sea level), whereas tropical storms can range upward to 10 to 15 or more feet above MSL.

Storm tides are formed when high, sustained winds push estuarine water out of upwind areas and pile it up against the opposite, downwind shoreline as large water ramps (Figure 5.1, page 59). The raised water floods adjacent lowlands. Wind waves on top of this sloping ramp erode the shoreline and cause property damage to marinas and inland structures. The sloped water ramp will be maintained as long as there is a wind holding it up. When the wind diminishes, the water will flow back down the ramp to its original flat surface.

The height of the sloped water ramp, plus the wave height, are controlling mechanisms for the location and rates of shoreline recession. Thus, on the high side of the ramp, the water level oversteps the sand beach, waves break directly on a sediment-bank shoreline, and erosion occurs. But, on marsh and swamp-forest shorelines, when the storm tides overstep the shorelines, wave energy is baffled and dissipated by the vegetation. In contrast, on the low side of the ramp, wave energy is harmlessly expended on sand beach shorelines. On marsh grass shorelines, the low side drops the water level below the tough root mass of the living grasses to allow waves to erode and undercut the older, soft peat sediment underneath. Ultimately, large blocks of marsh peat break off.

Even if a hurricane moves offshore of the barrier islands in a generally coast-parallel fashion without making direct landfall, the winds can create major estuarine storm tides. For example in 1993, Hurricane Emily grazed Cape Hatteras with sustained winds of 92 mph as it traveled northward. The counterclockwise winds of this storm blew the waters from the northern sounds southward across Pamlico Sound and piled it up in the bend behind Cape Hatteras. A maximum storm tide of 10.5 feet above MSL occurred between Buxton and Avon

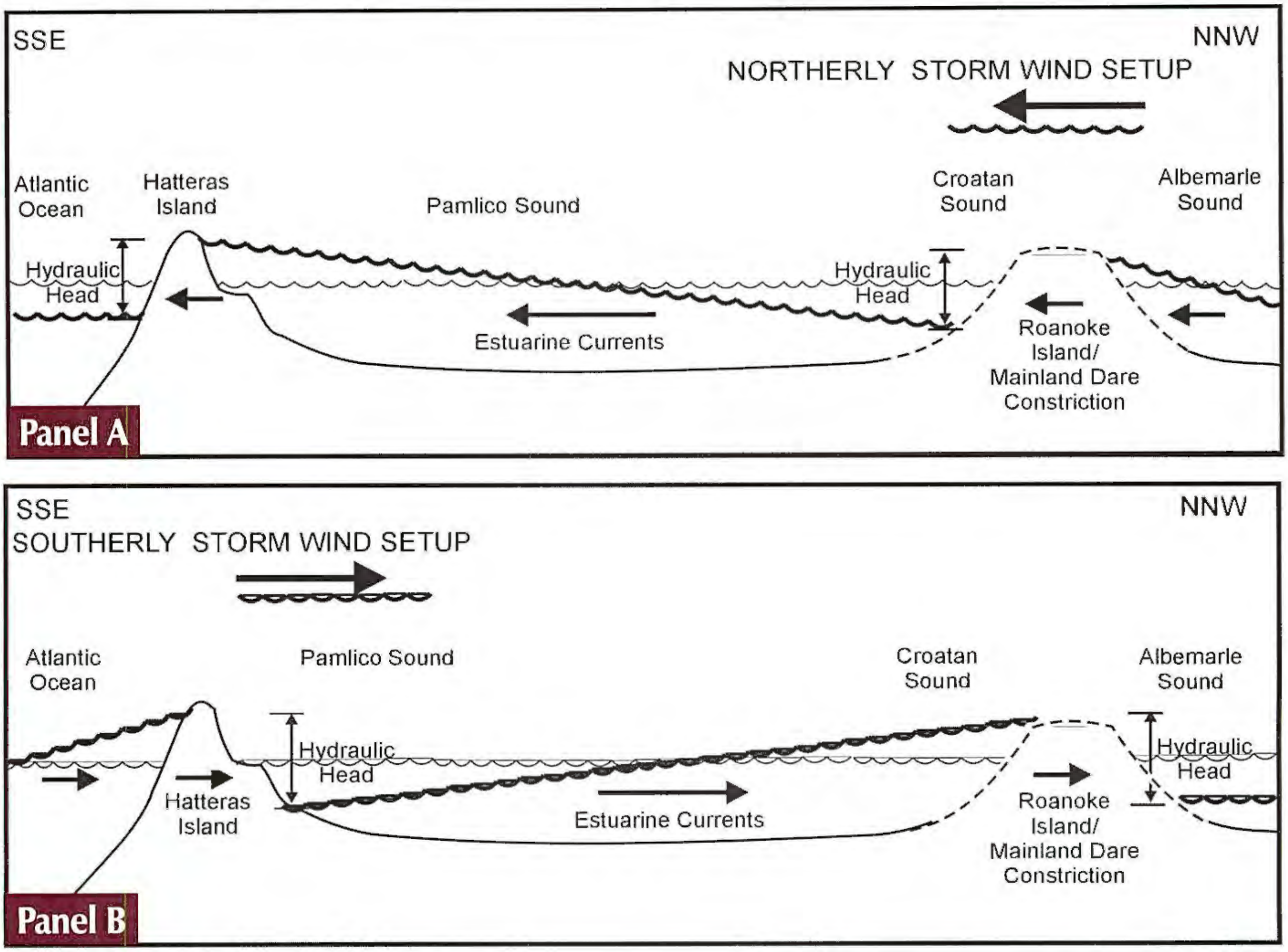


FIGURE 5.1. *Models of estuarine wind tides in the North Carolina sounds that form in response to different types of storm events. Wave energy superimposed upon either high or low storm tides results from storm events and is the primary process driving estuarine shoreline recession.* ***Panel A.*** *Storm tides resulting from events dominated by winds from the NE, N, or NW directions.* ***Panel B.*** *Storm tides resulting from events dominated by winds from the SE, S, or SW directions. These models are based upon the physical oceanographic studies of Pietrafesa et al. (1986), Pietrafesa and Janowitz (1991), and Lin (1992).*

and decreased gradually to the north and south. Severe erosion damage was caused by flooding while wind damaged the Buxton maritime forest.

Hurricanes that make a direct landfall across the coast in the southern province have a significant impact upon the estuarine waters throughout North Carolina. In 1996, Hurricanes Bertha and Fran made direct landfall between Wrightsville Beach and Onslow Beach. The estuarine storm tides in the landfall area were related to the ocean-side storm tide that readily spilled over the barrier islands and poured through the numerous inlets. The back-barrier estuaries received storm tides that were up to 14 feet above MSL. These two storms also had a significant impact upon the trunk estuaries in the northern province. The counterclockwise winds along the north side of the storms blew the water westward in the trunk estuaries. This resulted in storm tides up to 10 feet above

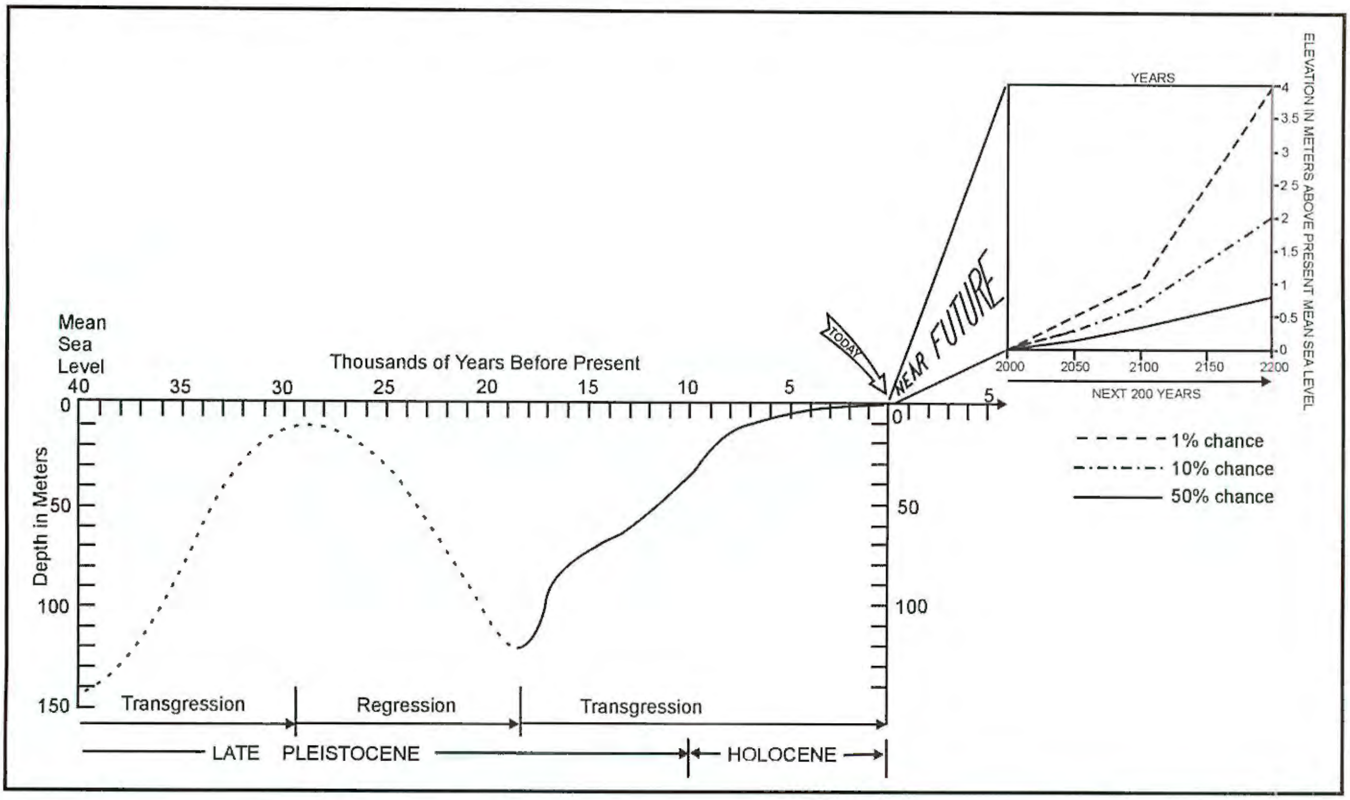


FIGURE 5.2. *Generalized sea-level curve for the last 40,000 years of Earth history, including the late Pleistocene, Holocene (the last 10,000 years), and extending 100 years into the near future. The 40,000-year curve is modified from Curray (1965), and the near future curve is based upon data from IPCC (1990) and Titus and Narayanan (1995). Three potential curves are plotted for the near future and represent predictions with different probabilities that are dependent upon how fast global warming becomes a major factor in the earth's climate. These curves represent average worldwide sea-level rise that will result only from global climate change and do not include sea-level rise from other regional factors such as changes due to land subsidence or uplift, etc. Therefore, the three curves are conservative and only represent the extent to which climate change will accelerate the rate of sea-level rise. The solid or most conservative line is similar to what the IPCC (1990) considers its "business as usual" sea-level prediction. For example, the rate of sea-level rise for North Carolina, based upon tide-gauge data over the past decades (see Figure 5.5), ranges between 1.01 to 1.5 ft/100 yrs (3.1 mm/yr to 4.6 mm/yr), which is similar to the 50% chance of projected rate of sea-level rise. Thus, if sea-level rise continues at its present rate, there is a 50% chance that with global warming, the N.C. coastal region could experience a two or more times increase in the rate of present sea-level rise by 2200 AD.*

MSL with significant waves superimposed upon the water ramp that seriously flooded and battered the upper reaches of the Neuse and Pamlico River estuaries.

Hurricanes that cross the coast in the northern province will produce storm tides that slosh back and forth in the estuaries impacting both the inner and outer portions. The initial winds will often blow the waters up the estuaries, producing low-wind tides along the barrier islands and high-wind tides in the upper reaches of the trunk estuaries. As the storm passes and storm winds come from the opposite direction, there is a rapid back flow of high water, resulting in catastrophic coastal consequences on the barrier islands. Historically, walls of water that are 10 feet or higher have moved back upon the Outer Banks as the hurricane passed, wrecking havoc on the sound side and often blowing open new inlets through the barrier islands.

Effects of Storm-Tide Flooding

Coastal flooding by salt water has numerous consequences. Salt water is toxic to freshwater plants. Consequently, storm winds containing salt spray and salty flood waters may either kill the vegetation directly, or stress it to the point that it becomes vulnerable to post-storm diseases. The extent of saltwater kill in the outer and inner estuary depends upon the salinity. The saltier the water, the greater the impact will be. Both the salt water and high-energy waves from extremely large storm tides may severely impact the trees and shrubs that occur in vegetative fringes along many sediment-bank shorelines. Killing and eroding this protective vegetative fringe commonly reactivates the erosional processes along a temporarily stable shoreline.

Seven hurricanes directly impacted the North Carolina coast between 1996 and 1999, with local estuarine storm surge up to 12 feet above MSL. The cumulative impact of multiple storms resulted in extremely severe erosion in the upper reaches of the trunk estuaries where shoreline erosion locally ranged from tens to hundreds of feet. The first storms in 1996 took out a lot of vegetation on sand beaches, increasing the exposure of adjacent sediment banks. Large storm surges of subsequent storms overstepped the sand beach and severely undercut and eroded the high banks and bluffs. This, in combination with saturated ground from heavy rainfall and high winds, caused massive slumping of the sediment banks onto the beach. Also, the saturated ground and high winds severely impacted swamp-forest shorelines, blowing over many shallow-rooted trees along the outer edge.

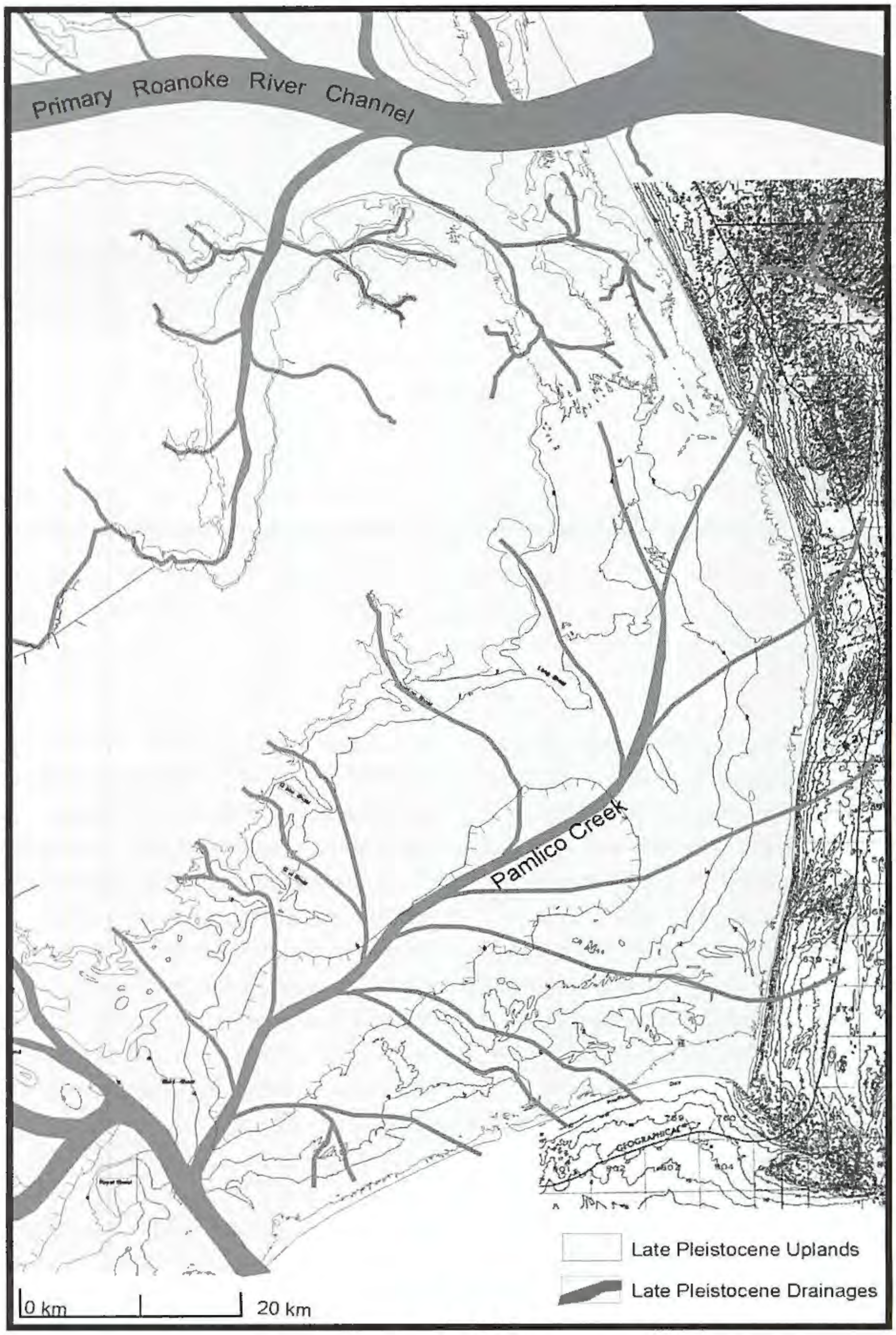


FIGURE 5.3. Reconstruction of the paleotopography and paleodrainage system in northeastern North Carolina during the last Pleistocene glacial maximum. This is what North Carolina looked like between 25,000 to 10,000 years ago when sea level was about 425 feet below present, and the ocean shoreline was on the continental slope between 10 to 60 miles east of today's coast. See the sea-level curve in Figure 5.2.

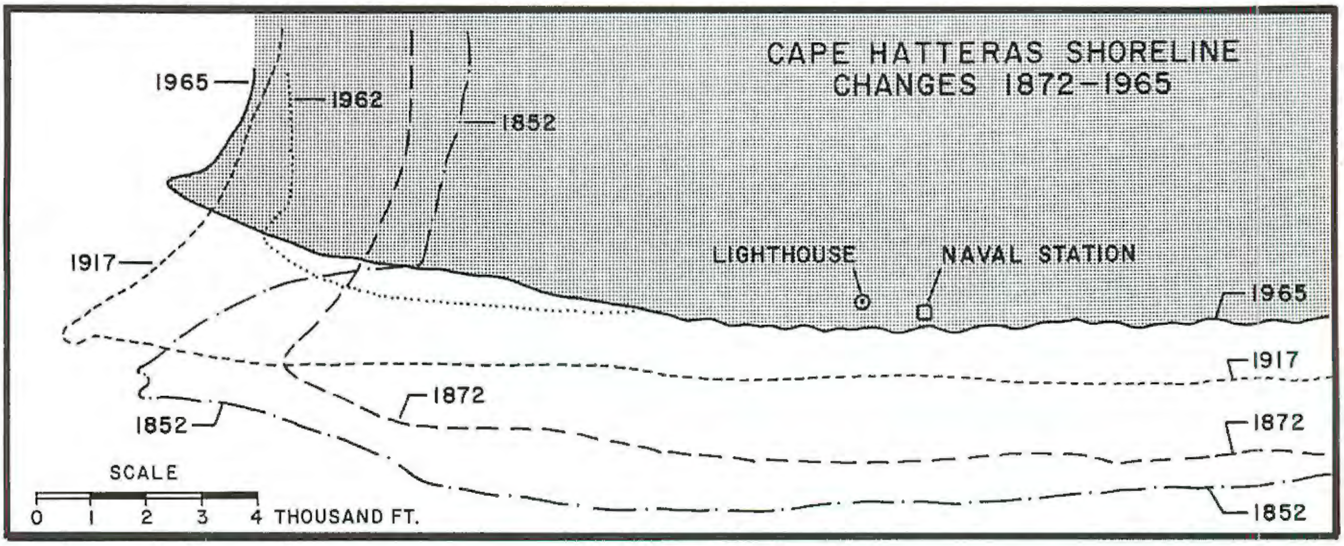


FIGURE 5.4. Map of ocean shoreline change from 1852 to 1965 by Fisher (1967) demonstrates the recession of the ocean beach at Cape Hatteras. About 3,000 feet of shoreline erosion in 113 years ultimately led to the decision to move the Cape Hatteras Lighthouse 1,600 feet back from the shoreline in 1999.

Shorelines with bulkheads and riprap were not immune to shoreline erosion problems resulting from these storms. Frequently, the structures were undercut, side flanked or overtopped, severely eroding the land from behind the structure and often destroying or at least damaging the structure itself. Unprotected properties adjacent to previously protected properties suffered major land losses that were accentuated as the stabilized property acted as a headland focusing much of the eroding energy into the adjacent land, resulting in development of cove-like shoreline features.

SEA-LEVEL CHANGE

Rising sea level slowly and systematically floods up the stream valleys and adjacent land slopes. However, it is wave energy during storms that physically erodes the shoreline and moves it further landward in response to rising sea level. A falling sea level results in the abandonment of an old shoreline as the contact between water and land slowly migrates seaward.

Development of North Carolina's modern coastal system occurred during the last 10,000 years. Prior to this time, the N.C. coastal system was located below the edge of the continental shelf or about 10 to 60 miles seaward of and 425 feet lower than the present shoreline (Figure 5.2). Figure 5.3 depicts the paleo-drainage that existed 10,000 years ago in the area of the present Outer Banks and Albemarle-Pamlico estuarine system.

As the climate warmed and the glaciers began to melt and recede, sea level began to rise. Thus, the shoreline and coastal system generally migrated upward and westward throughout much of the Holocene. The flooding process migrated the shoreline across the continental shelf to its present location. The estuaries formed as the rising sea flooded up the topographically low river and stream valleys.

Two types of data demonstrate that sea level has continued to rise over the past 150 years. A map (Figure 5.4) by Fisher (1967) displays historic shorelines that reflect a constant landward recession of the beach in the Buxton and Cape Hatteras area. Data from long-term tide gauge records (Hicks et al., 1983; Gornitz and Lebedeff, 1987; Douglas et al., 2001) demonstrate similar rates of sea-level rise for both Charleston, S.C., and Norfolk, Va. (Figure 5.5). These data suggest that sea level is rising at about 1.01 ft/century in the Charleston area and about 1.06 ft/century in the Norfolk area. These data demonstrate that sea level is continuing to rise resulting in the ongoing flooding of low coastal land and ubiquitous recession of North Carolina's

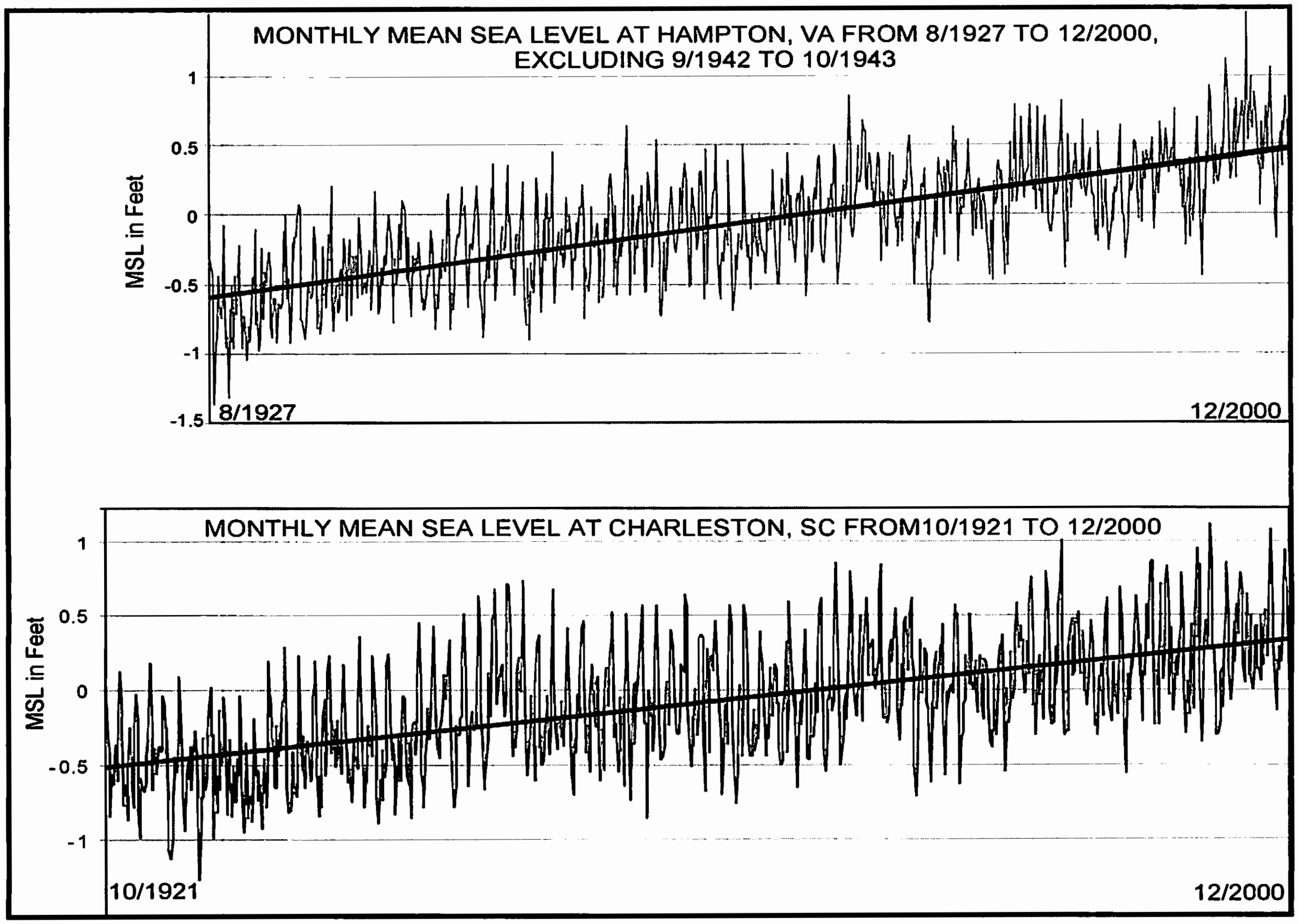


FIGURE 5.5. Tide gauge data from Hampton, Va., and Charleston, S.C., demonstrate the rate of ongoing sea-level rise. The plotted data are monthly averages of mean sea level that extend from 8/1927 and 10/1921, respectively, to 12/2000. The heavy line through each plot is the graphical representation of the trend of data in a series. It is obtained by regression analysis and shows the net rise in sea level during this time period. Similar tide-gauge data developed at Duck, N.C., by the U.S. Army Corps of Engineers only goes back to 1980, but during this 20-year time period, the data suggest a slightly higher rate of sea-level rise of about 1.5 ft/100 yrs for the Albemarle Sound coastal region. The tide-gauge data are from the National Oceanic and Atmospheric Administration (NOAA) National Water Level Observation Network and are available online. ***Panel A.*** *The tide-gauge data for Norfolk, Va., suggests sea level has been rising at the rate of 1.16 ft/100 yrs in this region since 1927.* ***Panel B.*** *Tide-gauge data for Charleston, S.C., suggests sea level has been rising at the rate of 1.01 ft/100 yrs in this region since 1921.*

coastal shorelines.

A major issue raised by the Intergovernmental Panel on Climate Change Report (IPCC, 1990) concerns the potential impact of global warming upon the magnitude and rate of sea-level rise over the next few decades to century. Increased rates of sea-level rise will adversely impact coastlines of North Carolina in many different ways:

- accelerated rates of coastal erosion and land loss;
- increased economic losses due to flooding and storm damage;
- increased loss of urban infrastructure
- total collapse of some barrier island segments; and
- increased loss of estuarine wetlands.

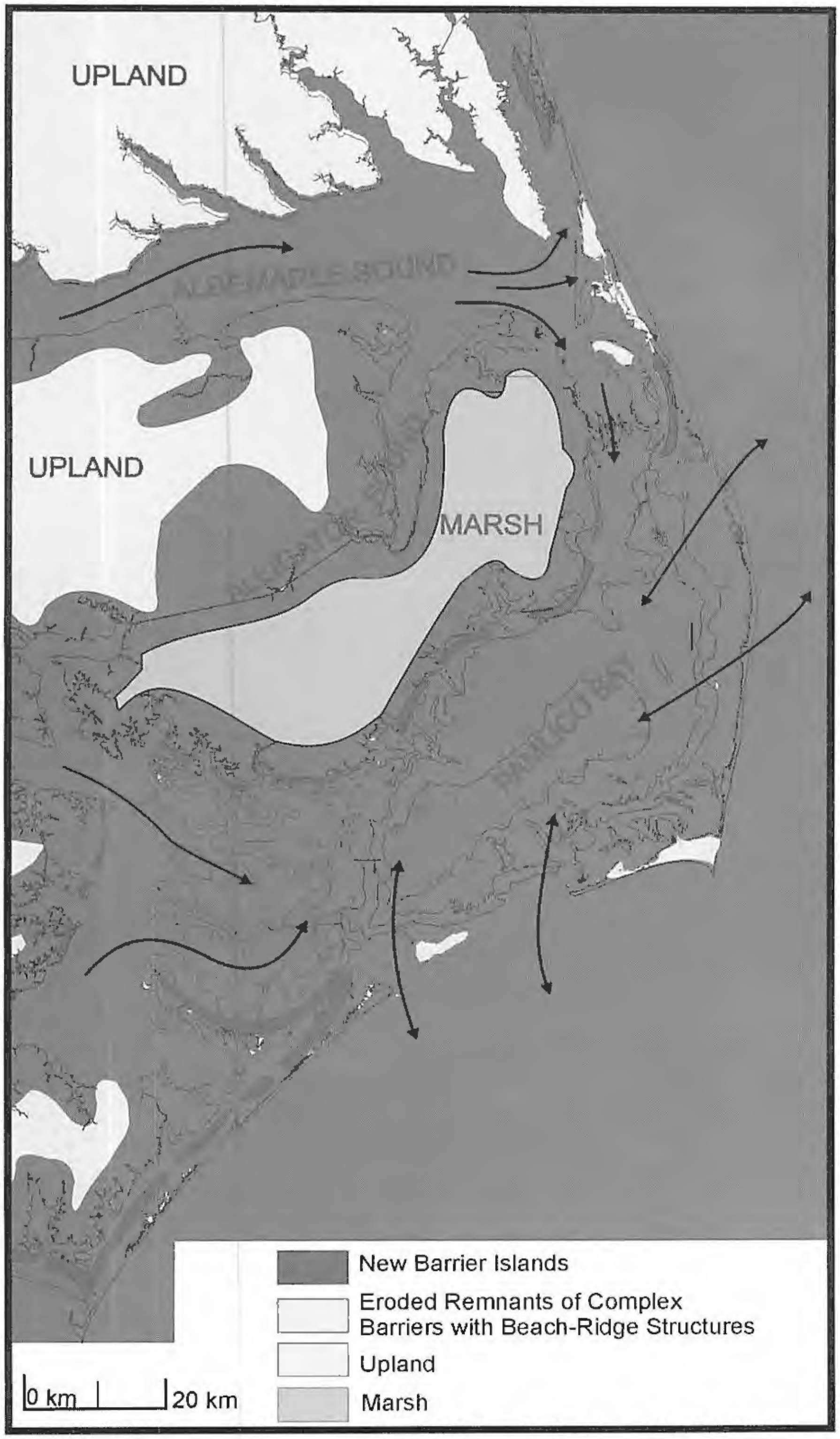
As glacial ice in Antarctica and Greenland continues to melt in response to global climate warming, the ongoing rise in sea level will continue to flood the coastal lands of North Carolina.

Sea level is rising in the state at about 1 foot/century. Is this rate of flooding significant for the N.C. coastal system? On your next trip through the outer coastal plain, notice how low and flat the land is with extensive, water-filled drainage ditches occurring adjacent to the highways. The water in these ditches is generally at or close to sea level, and the roads are built on fill dirt dug from these ditches. The result is a coastal system in the northern province with a complex of broad, shallow estuarine environments that extend up to 100 miles into the coastal plain.

Due to the very low regional land slope, the ongoing rate of sea-level rise produces major shoreline recession. With continued flooding, the coastal system will maintain its general appearance and characteristics through time as it slowly migrates upslope and landward by a gradual evolutionary succession.

The present predicted rates of sea-level rise from global warming by the

FIGURE 5.6. *Prediction for the initial collapse of barrier island segments within northeastern N.C. in the short-term future (i.e., next few decades) if sea level continues to rise at either the present rate or greater (see the sea-level curve in Figure 5.2) and the quantity and magnitude of storms that have characterized the 1990s continues or increases. The portions of the barrier islands that will collapse are the simple overwash barriers that are severely sediment starved and are characterized by severe shoreline erosion problems.*



year 2100 range up to 2.8 to 3.2 feet/century (Titus and Narayanan, 1995; Warrick et al., 1996), with a large uncertainty due to the unknown contribution of ongoing global warming. If these predicted values turn out to be correct, the N.C. coast is in for some serious consequences. The two new maps displayed in Figures 5.6 and 5.7 are predictions of shoreline change in coastal North Carolina, based upon 35 years of research by Riggs. Large segments of the Outer Banks are already collapsing as evidenced by the lack of space to maintain a viable coastal N.C. Highway 12 along specific segments. Figures 2.14A and 2.14B (page 21) reflects this ongoing collapse of sediment-starved weak portions of the Outer Banks. If the present rate of sea-level rise continues and the storm pattern of 1996 through 1999 persists, then a new coastal figuration could be realized within a decade (Figure 5.6) and by the end of 2200 A.D (Figure 5.7). However, if global warming increases resulting in an increased rate of sea-level rise, the character of the N.C. coast indicated in these figures could be realized in a shorter time frame.

FIGURE 5.7. *Prediction for the long-term future character of the barrier islands and associated estuaries within northeastern N.C. (i.e., next few centuries). This scenario would be realized if sea level continues to rise at either the present rate or increases in response to predicted rates of global warming and associated sea-level rise (see the sea-level curve in Figure 5.2) or one or more very large coastal storms (category 4 and 5 hurricanes) directly impact the Outer Banks.*

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Facing page: An actively eroding low sediment-bank shoreline with a narrow strandplain beach is along the Cape Fear River estuary.

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The author and graduate students have carried out an extensive research program concerning the origin and evolution of the N.C. coastal system for the late Pleistocene and Holocene (the last 20,000 years of earth history). This program began in the early 1980s and continues today and has included the following primary graduate students: Gary Eames, Stephen Fournet, Richard Moore, Megan Murphy, Greg Rudolph, Eric Sager, Angela Sproat, Robert Wyrick, and Douglas Yeates. Various aspects of this research program have been funded by the U.S. National Science Foundation, the U.S. National Oceanic and Atmospheric Administration — National Undersea Research Program, U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Department of Defense, N.C. Albemarle–Pamlico Estuarine Study, North Carolina Sea Grant College Program, N.C. Geological Survey, and East Carolina University. These studies have provided the database for the geologic framework and process-response dynamics of the coastal system.

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Photos by Stanley R. Riggs, Lundie Spence and Scott D. Taylor; graphics by Dorothea Ames
Front Cover Photo: An actively eroding sediment-bluff shoreline is along a "ditched" navigation channel excavated through the uplands.

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