FIGURE 7-1-1. Historical maps depicting the evolutionary changes for Croatan Sound and opening of Roanoke Marshes between Croatan and Pamlico Sounds. Notice the dramatic changes in inlet location through the barrier islands, the habitat changes within Croatan Sound due to current scour, and the slow dissection of Stumpy Point Lake by the receding shoreline. Maps are not to the same scale. **PANEL A.** Map of Moseley dated 1733. **PANEL B.** Map of Collet dated 1770. **PANEL C.** Map of Price and Strother dated 1808. **PANEL D.** Map of MacRae and Brazier dated 1833. All four maps are from Cumming (1966).

FIGURE 7-1-2. Longitudinal cross section along the channel thalweg of Pamlico Creek on the south, across the interstream divide at Roanoke Marshes, through the channel thalweg of Croatan Creek, and into the Roanoke River on the north. This section shows the general antecedent or paleotopography of the Pleistocene surface and thickness of Holocene sediment that infilled the channel in response to estuarine flooding by rising sea level during the past 10,000 years. Figure is modified from Riggs et al. (2000).

FIGURE 7-1-3. Side-scan sonar images of Croatan Sound bottom showing relict geologic units exposed on the sound floor. All images are about 200 meters in width. **PANEL A.** A scour channel located in the center span of the old Croatan bridge (U.S. Highway 64) shows linear dark gray patterns (areas of low reflectance) resulting from the exposure of organic-rich mud sediments. These mud sediments infilled Croatan Creek during estuarine flooding in response to rising Holocene sea level. Today, these muds are being severely eroded by the modern flow channel displayed in bathymetric profiles on Figure 7-1-4. Also, notice the linear white sand deposits (areas of high reflectance) that occur in the lee (south) of each bridge piling. The broad white reflectance pattern on the north side of the bridge is the sonar shadow with refraction patterns from the bridge pilings. **PANEL B.** A shallow, sand-covered Pleistocene platform on the western side of old Croatan bridge (see bathymetric profiles on Fig. 7-1-4). The extensive white pattern is due to the high reflectance character of quartz sand that dominates the platform tops with sand waves having about 10 meter wavelengths. Also, notice the linear scarp that has been eroded into an older mud or peat sediment unit buried below the surficial sand to the east. **PANELS C and D.** The highly irregular, mottled pattern is the erosional character of marsh peat that crops out on the sound bottom along the southwest side of Roanoke Island. These are the basal remnants of the Roanoke Marshes peat deposits. The peat deposit is dissected by paleo-tidal creeks (smooth areas) that were backfilled with soft mud and very fine sand. These channel fill muds erode faster than the associated peat producing lower depressions. The dark gray pattern of peat, closest to the center line, grades to white away from the center line, due to the shadow effect of eroding 3-D peat blocks on the sound floor. The peat blocks range from 1 to 5 meters across with vertical relief up to 1 meter. See Figure 7-1-2 for the general location of these eroded peat remnants of Roanoke Marshes.

FIGURE 7-1-4. Composite of four bathymetric profiles along the south side of the old Croatan bridge (U.S. Highway 64). The profiles include a general interpretation and reconstruction for 1817 based upon old maps (see Fig. 7-1-1), the U.S. hydrographic Survey profile H257 of 1851, a 1954 N.C. Department of Transportation profile made during the pre-construction survey along the proposed bridge location, and an October 1997 profile from Rudolph (1999). Comparison of these profiles supply the baseline information concerning shoreline and bathymetric changes along the old Croatan bridge corridor through time. Figure is modified from Riggs et al. (2000).

FIGURE 7-1-5. Portion of a satellite image (EOSAT from SPACESHOTS, Inc.) of the Cedar Island area showing the modern process of drowning across the Carteret Peninsula interstream divide. The vast Cedar Island *Juncas roemarianus* marsh (gray color) occurs on the interstream divide between West Thorofare and Thorofare Bays. With continued flooding due to rising sea level and shoreline erosion, the marsh will rapidly disappear and eventually form an open Thorofare Sound. This is a modern analog for the transition of Croatan Creek to Croatan Bay and finally Croatan Sound.

FIGURE 8-1-1. Map shows the location of estuarine shoreline erosion sites in northeastern North Carolina included in the present study (Chapter 8).

FIGURE 8-2-1. Photographs of the Hatteras Overwash site. **PANEL A.** Looking east along the north side of the eroding marsh platform. The outer zone has been totally stripped of marsh grass during winter storms. **PANEL B.** Close-up of the peat surface in the outer zone that has been stripped of marsh grass and is now dominated by green algae. **PANEL C.** Close-up of outer edge of eroding marsh platform with a large eroded peat block lying in the adjacent shallow waters. The marsh grass is *Spartina alternaflora*. Photograph is from Murphy (2002). **PANEL D.** Looking east along the inner zone of the marsh platform and the adjacent zone of scrub-shrub that occupies the higher elevation of a more recent overwash fan. Notice the extensive accumulation of wrack along the inner zone of the *Juncus roemarianus* marsh platform. **PANEL E.** Looking west along the strandplain beach associated with an overwash fan that occurs to the immediate west of the marsh platform. Notice the minor amounts of dead submerged aquatic vegetation (SAV) that has accumulated locally on this summer beach. **PANEL F.** Same location as Panel E, but now the fall strandplain beach is covered with an extensive accumulation of dead SAV.

FIGURE 8-2-2. The Hatteras Overwash site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1962 and 1998.

FIGURE 8-2-3. The Hatteras Overwash site aerial photograph time slices from 1945, 1962, and 1989. The 1945 photo predates construction of N.C. Highway 12 and regular maintenance of the associated barrier-dune ridges. Consequently, this barrier segment is dominated by active overwash processes. However, in the 1962 post-Ash Wednesday storm photograph, the overwash is significantly diminished in magnitude. The difference probably reflects the presence of an elevated N.C. Highway 12 roadbed and reconstruction of the associated barrier-dune ridge. The 1989 photo shows no overwash due to a major barrier-dune ridge with increased vegetation growth along the landward side.

FIGURE 8-2-4. Photographs of the Buxton Inlet site. **PANEL A.** Summer photograph looking north along the backside of the marsh platform with *Spartina alternaflora* in bright green and *Juncus roemarianus* in dark green colors. **PANEL B.** Winter photograph looking north along the backside of the marsh platform with the marsh grasses partially eroded off the peat surface. Notice the scarped outer marsh edge and the irregular geometry to the marsh shoreline due to active shoreline erosion processes. **PANEL C.** Winter photograph looking south along the marsh platform. Notice that there is some sand available to form a high water sand berm on top of the marsh platform. **PANEL D.** Summer photograph looking north along the backside of the marsh platform. Notice the abundant sand available to form a major strandplain beach in front of and temporarily protecting the outer scarped marsh. Also, notice the dead submerged aquatic vegetation (SAV) that formed wrack berms at three different previous water levels. Photograph is from Murphy (2002). **PANEL E.** Winter photograph looking east across the inner portion of the marsh platform, the narrow scrub-shrub zone, and the newly constructed barrier-dune ridge on the east side of the new N.C. Highway 12. Notice the beach berm in the lower right hand portion of the photo that is composed of a lower sand component and two upper SAV wrack components. Also, behind the wrack berms is an irregular patch of rafted wrack within the transition zone vegetation. **PANEL F.** Looking east at the newly constructed and vegetated barrier-dune ridge built to protect the post-Hurricane Dennis (1999) N.C. Highway 12 relocation. These structures eliminate the overwash and inlet processes that built this portion of the barrier island and are necessary for maintaining the island for the long term. Without overwash and inlet processes supplying sand to the estuarine side, estuarine erosion rates increase causing the barrier to narrow through time.

FIGURE 8-2-5. PANEL A. A 1992 oblique aerial photograph looking north towards Avon and showing three previous locations of N.C. Highway 12, two of which are "going-to-sea" highways. Notice the small marsh platforms that occur along the back side of the barrier. The dark vegetation occurring between the marsh platforms and upland overwash fans, is dense scrub-shrub growing around the outer lobe of older overwash fans. **PANEL B.** A 1999 post-Hurricane Dennis aerial photograph (N.C. Department of Transportation) showing N.C. Highway 12 (#3) "going to sea" and the newly relocated N.C. Highway 12 (#4). The new highway was built on the west side of the power lines in the 1992 photograph. However, there is no room to move the road further west in the future, as the island continues to narrow in response to shoreline erosion that is taking place on both sides of the barrier.

FIGURE 8-2-6. The Buxton Inlet site 1998 Digital Orthophoto Quarter Quardrangle (DOQQ) with digitized shorelines for 1962, 1974, and 1998.

FIGURE 8-2-7. The Buxton Inlet site aerial photograph time slices from 1962, 1964, 1983, and 2000. In the post-Ash Wednesday nor'easter storm aerial photo of 1962, notice the extensive overwash zone and the newly opened Buxton Inlet. In the 1964 photograph, notice the extensive sand body, or flood-tide delta, that developed on the sound side behind Buxton Inlet. The Inlet was closed by the U.S. Army Corps of Engineers using sand dredged from the dark rectangular holes in the flood-tide delta immediately behind the former inlet. In the 1983 and 2000 photos, notice the two different segments of N.C. Highway 12 on the left side of the photo that were sequentially relocated prior to each photograph. Also, notice the numerous and extensive sand mines (red stars in 2000 photo) that were dredged up to 20 feet deep between 1964 and 1983. The sand was used to close the inlet and for several ocean beach nourishment projects. The deep holes allow for increased wave action adjacent to the estuarine shoreline and prevents existing offshore sands from moving into the back-barrier system, causing increased rates of estuarine shoreline recession.

FIGURE 8-2-8. Photographs of the Salvo Day-Use site. **PANEL A.** Winter photograph looking north along the outer portion of the peat platform. Low wind tide has exposed the eroding wave-cut scarp in peat along the front side of the marsh platform. Notice that the outer zone is stripped of marsh vegetation by storms and is rapidly colonized by green algae. **PANEL B.** Winter photograph looking south along the outer portion of the peat platform during low wind tide. Notice how different layers of peat are eroded off in a stair-step fashion and the occurrence of a high water berm composed of dead submerged aquatic vegetation (SAV) with no sand. **PANEL C.** Close-up of the eroding marsh during a low wind tide. Notice the tough modern root mass forms a sloping overhang (on the left side of the photo) as the softer underlying peat (visible on the lower right side) is easily eroded. **PANEL D.** Close-up of a block of the modern, root-bound, upper peat surface as it begins to finally crack and break off. **PANEL E.** Summer photograph of the very narrow *Spartina alternaflora* marsh platform in front of a sand upland dominated by maritime forest and the Salvo cemetery. Notice the occurrence of a high-water level, thin sand berm perched on top of the marsh platform and a low-water level, SAV wrack berm without any sand. Photograph is from Murphy (2002). **PANEL F.** Winter photograph taken at the same spot as Panel E. Notice that there are two SAV wrack berms with most of the sand gone that was associated with the upper sand berm in the previous photo. Also, the marsh grasses have been mostly stripped off the peat surface due to winter wave action.

FIGURE 8-2-9. The Salvo Day-Use site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1962 and 1998.

FIGURE 8-2-10. The Salvo Day-Use site aerial photograph time slices from 1962, 1978, and 1983. In the 1962 photograph, notice that even though N.C. Highway 12 and associated barrier dune ridges were in place prior to the Ash Wednesday nor'easter storm, the old overwash pattern was re-established as the cross-island water flowed into Pamlico Sound through the existing channel structures on either side of the study area. The ongoing process of estuarine shoreline erosion through time is obvious along the outer edge of the impoundment in the upper left portion of the photo sequence (1962 to 1983). By 1998 (Fig. 8-2-9) ongoing shoreline recession has eroded through the adjacent dike and exposed an ever increasing length of the north-south ditch to the open waters of Pamlico Sound.

FIGURE 8-2-11. Photographs of Jockey's Ridge site. **PANEL A.** An oblique aerial photograph showing Jockey's Ridge State Park and the irregular geometry of the estuarine low sediment bank shoreline. Photograph is from the Field Research Facility of the U.S. Army Corps of Engineers. **PANEL B.** Looking north along the eroding low sediment bank shoreline composed entirely of sand and covered with various types of grass vegetation. The low wind tide has exposed the extremely broad and well developed strandplain beach that consists of an upper portion occupied during high wind tides and a lower portion occupied during low wind tides. Notice the grassed slump blocks that have collapsed in front of the wave-cut scarp. **PANEL C.** Close-up view looking south along the eroding low sediment bank shoreline and associated upper strandplain beach. Rapid recession of the wave-cut scarp has required the observation platform, that was sitting on top of the low sediment bank, to be repiled and braced. Notice the exposed roots in the wave-cut scarp. **PANEL D.** Photo during a low wind tide from a marsh headland and looking east into a cove. The shoreline is a low sediment bank covered generally by pine trees and a very broad and well developed strandplain beach. **PANEL E.** Photo looking southwest from inside the cove towards the marsh headland of Panel D. The abundant dead pine trees in the nearshore and on the strandplain beach demonstrate the active rates of shoreline recession.

FIGURE 8-2-12. The Jockey's Ridge and Nags Head Woods sites 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1964 and 1998.

FIGURE 8-2-13. The Jockey's Ridge site aerial photograph time slices from 1962, 1971, and 1989. In 1962, the study site behind Jockey's Ridge was essentially all active sand dune with very little vegetation. Erosion of the dune field provided the sand for an extensive strandplain beach. A large portion of the dune field along Roanoke Sound became vegetated with pine and scrub-shrub through time, as indicated on the 1971 and 1989 aerial photographs. This changed the small-scale pattern of the shoreline from a smooth curved shoreline to the present irregular shoreline with numerous vegetated headlands and coves (Fig. 8-2-11).

FIGURE 8-2-14. Comparison of barrier island systems and the estuarine shorelines on aerial photographs from October 1932 and November 1999 for the northern portion of Nags Head including Jockeys Ridge and Seven Sisters Dune fields. This segment is a complex barrier island (Fig. 4-5-1B) that is not dominated by overwash. Thus, the back-barrier estuarine shoreline is not under the influence of oceanic processes. Rather, it totally responds to estuarine erosion dynamics similar to mainland estuarine system. **PANEL A.** This 1932 aerial photo predates any major shoreface modification such as construction of barrier dune ridges that would have inhibited the overwash process. However, N.C. Highway 12 had just been constructed and you can see the original beach houses built in the late 1800s along the ocean shoreline. Notice the village of Old Nags Head on the estuarine side of the island. The Jockey's Ridge and Seven Sisters back-barrier dune fields are extensive and very active. The photos were flown after a major nor'easter in March 1932 for the Beach Erosion Board (1935) as background data for a beach erosion study (Field Research Facility, U.S. Army Corps of Engineers). **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 massive urbanization that has minimized oceanic processes and allowed for the extensive growth of a major vegetative cover. Since the estuarine shoreline is dominated by erosion, wherever development occurs the shoreline has been extensively bulkheaded. However, the shoreline behind Jockeys Ridge consists of portions of the older back-barrier dune field that have been partially stabilized by vegetation. Consequently, this area is now in an erosional mode, resulting in a low sediment bank shoreline with a well developed sand strandplain beach. The photo was flown by the N.C. Department of Transportation to evaluate shoreline erosion and the condition of N.C. Highway 12 following Hurricane Dennis (9/1999).

FIGURE 8-2-15. The Seven Sisters Dune Field site in a 1932 aerial photograph (Field Research Facility, U.S. Army Corps of Engineers) with digitized shorelines (blue) and roads (red) from the 1998 DOQQ.

FIGURE 8-2-16. Photographs of Nags Head Woods site. **PANEL A.** Winter photograph looking northeast along the eroding edge of a narrow marsh platform towards a small segment of low sediment bank dominated by a maritime forest of pine trees. Notice the irregular erosional geometry of the marsh peat shoreline. **PANEL B.** Summer photograph looking the opposite direction to Panel A, southwest along the eroding edge of a narrow marsh platform that fronts an upland region dominated by a maritime forest of pine trees. The outer zone of marsh grass is a mixed assemblage of *Spartina patens* and *Juncus roemarianus*, while the inner zone of tall grass is *Spartina cynusoroides*. **PANEL C.** Close-up winter photograph looking southwest along the eroding edge of a marsh platform. Notice the two large eroded peat blocks sticking out of the water just to the right of the eroding shoreline. **PANEL D.** Close-up view of an eroding marsh peat headland along the shoreline in Panel C during a low wind tide. The deeply undercut modern root zone, slopes steeply into the water. A subsequent storm, with a high wind tide and wave action, will cause the overhanging block to break off and produce an offshore peat block as is seen in Panel C. **PANEL E.** Close-up view of low sediment bank shoreline that occurs in the distance in Panel A. The low wind tide has exposed the rippled sand flats of the lower portion of the strandplain beach. Notice the many trees with the root structures exposed by the erosional processes. **PANEL F.** Close-up view of a dead live oak tree on the lower portion of the strandplain beach. The entire root system has been exposed through the erosion of the upland soil.

FIGURE 8-2-17. The Nags Head Woods site aerial photograph time slices from 1940, 1964, 1975, and 1983. These photographs show the four major geomorphic components of this complex barrier island segment. In the 1940 aerial photograph, the modern beach prism and active back-barrier dune field were essentially uninhabited and only slightly vegetated. These two segments have since undergone major urbanization along with significant levels of vegetative stabilization by pines. Nags Head Woods, an older back-barrier dune field that contains a major maritime forest and abundant inter-dunal fresh-water lakes, has remained essentially unchanged through the same time period. The marsh peat platform has accumulated up to 10 feet of peat that is systematically burying the irregular paleotopography of the Nags Head Woods dune field in response to ongoing rise in sea level. Notice the long fingers of maritime forest (red color on the 1983 photograph) growing on the dune sands that extend across the marsh platform (dark green color). The Nature Conservancy's Roanoke Trail follows one of these features to the study site (red stars).

FIGURE 8-2-18. Photographs of the Duck Field Research Facility site. **PANEL A.** An oblique aerial photograph showing the densely vegetated character of the estuarine shoreline at the Duck site. The narrow, outer and lighter green colored zone is marsh grass, whereas, the darker zone between the marsh and N.C. Highway 12, is dense scrub-shrub growing on top of the low sediment bank.
Oblique aerial photograph is from the Field Research Facility of the U.S. Army Corps of Engineers. **PANEL B.** Winter photograph looking north along the strandplain beach towards the eroded low sediment bank scarp in the distance on the right side of the photo. Notice the fringing marsh consisting primarily of *Juncus roemarianus* in the foreground and *Phragmites australis* in the background. In the middle of the strandplain beach is a wrack berm composed of dead marsh grasses. **PANEL C.** Summer photograph looking east across the shoreline to the upland scrub-shrub. The shorter grass in the foreground is *Juncus roemarianus* with *Phragmites australis* in the background.

FIGURE 8-2-19. The Duck Field Research Facility 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1986, 1992, and 1998.

FIGURE 8-2-20. The Duck Field Research Facility site aerial photograph time slices from 1986, 1992, 1997, and 2000. Notice how the fringing marsh along this low sediment bank shoreline fluctuates through time. In 1986, the fringing marsh occurs only in the southern section of the study area and by 1992 there is no fringing marsh in the study area. A very wide and dense fringing marsh occurs throughout the entire study area in 1997 and by 2000, the shallows in front of the access area (red stars) have opened slightly.

FIGURE 8-3-1. Maps of northern Roanoke Island showing the average annual estuarine shoreline erosion rates by shoreline segment, shoreline types, types and locations of shoreline erosion control structures, and the relationship between erosion rates and distance of open water (fetch) that impact different shoreline segments. Actual erosion rates for any given shoreline segment are dependent upon the type of shoreline in concert with the fetch and a whole series of other variables (see chapter 5). **PANEL A.** Map shows the average annual estuarine shoreline erosion rate data of Dolan and others (1972, 1986). The erosion data generally predate the construction of most erosion control structures. Due to the high erosion rates, much of the shoreline has now been armored and is now relatively stable but without sand beaches (Fig. 8-3-2B). The map also shows the location and type of structures, as well as the distribution of shoreline types used in the present study. **PANEL B.** Map showing the differences in amount of fetch around the northern end of Roanoke Island.

FIGURE 8-3-2. Photographs of the north Roanoke Island site. **PANEL A.** March 2001 photograph looking east along the bluff to high sediment bank shoreline of segment 6 (Fig. 8-3-1A). Photo is from Dough Cemetery at the east end of segment 5 containing the rock revetment. The eroding bluff shoreline decreases in elevation to a high sediment bank in the easterly direction. Notice the extensive overhang of the modern root-bound soil mat. This overhang will ultimately collapse, dropping the associated trees onto the bluff and strandplain beach where the continuous supply of trees and shrubs provides an evolving natural debris groin field. The increased size of the strandplain beach in the distance marks the beginning of segment 7 containing a wooden groin field. **PANEL B.** March 2001 photograph looking east along the rock revetment of segment 5 (Fig. 8-3-1A). The rock revetment was built in 1980 by the U.S. National Park Service to abate the 22.4 ft/yr of shoreline recession between 1969 to 1975 (Table 8-3-1). Notice that there is no strandplain beach in front of this rock revetment. **PANEL C.** June 2001 photograph looking west along eroding sediment banks of segment 6 (Fig. 8-3-1A). The photo shows the amount of recession of the unmodified sediment bank shoreline (segment 6) since 1980. **PANELS D and E.** March 2002 close-up views of the wave-cut scarp along segment 6 (Fig. 8-3-1A). Notice that the bluff is composed entirely of clean sand except in the zone labeled as a paleosol where a thin layer of sand is bound by organic matter and stained by iron oxide. Due to the composition, large blocks of sand slump off the bluff and form a sediment apron along the back side of the strandplain beach (below the white dashed lines). During subsequent high tides, waves systematically erode the slump aprons, forming the cuspate scarps and reworking sand into the strandplain beach.

FIGURE 8-3-3. The north Roanoke Island site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1969, 1975, and 1998.

FIGURE 8-3-4. The north Roanoke Island site aerial photograph time slices from 1969 and 1994. Crab Claw Spit formed over time from high rates of sediment bank erosion on the north end of Roanoke Island and the associated long-shore currents driven by northwest storms. However, during the latter part of the twentieth century, the amount of sediment feeding Crab Claw Spit rapidly diminished as most of the north end of Roanoke Island was stabilized (Fig. 8-3-1A). Loss of the sediment source led to destabilization, breakup, and rapid eastward migration of the Spit remnants as demonstrated in the 1994 photo. As the Spit moves, shorelines formerly protected behind the Spit, become re-exposed to open water and increased rates of shoreline erosion. The red star marks the same spot on both photographs.

FIGURE 8-3-5. Photographs of the Woodard's Marina site. **PANEL A.** Summer photograph looking south into the three common zones that characterize swampforest shorelines. The photo is taken from within the ghost swampforest of zone 3 and backed by the dense growth of *Spartina cynosuroides* that characterizes the middle zone 2 that is utilized as the shoreline. Behind the marsh grasses is the dense and living swampforest of zone 1. **PANEL B.** Winter photograph looking west along the swampforest shorelines from the same general location as Panel A. **PANEL C.** Close-up photo of the shoreline (zone 2) characterized by a small sand berm upon which supports the dense growth of *Spartina cynosuroides*. Photograph is from Murphy (2002). **PANEL D.** Close-up photo of the cypress trees and associated knees that are the last survivors within zone 3 as the shoreline of zone 2 moves landward.

FIGURE 8-3-6. The Woodard's Marina site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1963 and 1998.

FIGURE 8-3-7. The Woodard's Marina site aerial photograph time slices from 1956, 1978, 1989, and 2000. Notice the dense swampforest vegetation associated with the stream valleys of the many small drainage systems flowing into Albemarle Sound. A small, classic drainage system occurs within the boxed area on the 1956 aearial photograph. Notice that a very prominent cypress headland (red stars) occurs where the main stem of this stream intersects the Albemarle Sound shoreline. The shoreline within the cove west of this cypress headland is a low sediment bank that is in agricultural production. Compare the location of this cove through time as the low sediment bank recedes more rapidly than the adjacent swampforest shoreline. Due to the geometry of the drainage system, the length of swampforest shoreline increases through time at the expense of the sediment bank shoreline, along with a significant increase in the distance the cypress headland extends into Albemarle Sound.

FIGURE 8-3-8. Photographs of the Grapevine Landing site. **PANEL A.** Summer photograph looking north along the swampforest shoreline of the Alligator drowned river estuary. This swampforest shoreline has been extensively modified by natural processes resulting in a broad shoreline zone of marsh and strandplain beaches. The photo shows the southern portion of the study area, the landing (pier) in the center, and the northern portion of the study area in the distance. **PANEL B.** Winter photograph looking south across the southern portion of the study area from the pier. The outer zone of marsh grass is generally *Juncus*, whereas the inner zone occurring within the swampforest is generally *Spartina cynosuroides*. **PANEL C.** Close-up of strandplain beach within a cove formed by a small headland formed by a series of stumps and covered with *Juncus* marsh grass. Photograph is from Murphy (2002). **PANEL D.** Close-up of an eroded section of swampforest with the root systems exposed and *Spartina cynosuroides* marsh grass within the existing swampforest. Photograph is by M. Murphy. **PANEL E.** Close-up of a strandplain beach within a cove formed by a headland of swampforest trees that have been recently uprooted. The strandplain beach consists of a thin, basal bed of quartz sand burying the eroded peat substrate. The denser quartz sand has been buried by a one-foot thick accumulation of very light organic detritus. **PANEL F.** Close-up of the depositional and erosional sediment structures produced in the organic detritus layer on the strandplain beach during the last falling wind tide. The coffee-colored water is visible at the bottom left corner of the photo.

FIGURE 8-3-9. The Grapevine Landing site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1981 and 1998.

FIGURE 8-3-10. Photographs of the Point Peter Road site. **PANEL A.** Winter photograph looking west at the former fresh-water swampforest shoreline that has recently evolved into fresh- to low brackish-water transition zone and marsh vegetation. Today, the vegetation is dominated by *Spartina patens*, *Cladium*, *Baccharis*, and *Myrica*. **PANEL B.** Close-up of the highly irregular eroding geometry of the peat shoreline. The small headlands are held up either by modern *Baccharis* and *Myrica* stumps that occur at the shoreline as it recedes or by larger stumps and logs that occur in the lower portions of the eroding peat bank. **PANEL C.** Close-up of the irregular peat shoreline displaying the tops of the abundant, large, eroded peat blocks that litter the near-shore area. Notice the irregular wrack berm on top of the *Spartina patens* marsh. **PANEL D.** Close-up view of erosional wave action that causes the upper and overhanging modern root-bound layer to oscillate as the softer, decomposing under layer is actively eroded away. **PANEL E.** Similar photo to Panel A, but with a small strandplain beach composed totally of organic detritus eroded out of the underlying peat bed. The presence and extent of this organic detritus is extremely variable and dependent upon the season and storm patterns. Notice how the irregular erosional geometry of the original peat shoreline can be seen on the landward side of the strandplain beach. **PANEL F.** Winter photograph looking north from the same location as Panel E. Now the entire eroding peat shoreline is buried beneath an extensive strandplain beach composed totally of organic detritus. This detrital accumulation is over three feet thick at the waters edge and extends some distance seaward below the waters surface. Notice the beautiful detailed, and small-scale depositional and erosional sediment structures that are preserved on this beach as the water rises and falls in response to the wind tides.

FIGURE 8-3-11. The Point Peter Road site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1969 and 1998.

FIGURE 8-3-12. The Point Peter Road site aerial photograph time slices from 1969, 1983, 1998, and 2000. Notice that the impoundment north of Point Peter Road is separated from Pamlico Sound by a major outer ditch and associated dike. Comparison of land loss along the outer ditch between the 1969 and 1983 photographs demonstrates the rapid rate of shoreline recession. The ditch is long gone by 1998 and the impoundment has reverted to the natural vegetation pattern. Also, notice the major expansion through time of transition zone and marsh vegetation (light gray-green color on the 1983 to 2000 photographs) at the expense of the swampforest vegetation (red color on the 1983 and 1998 photos and dark green on the 2000 photographs). This is interpreted to be the drowning of these low-lying wetlands in direct response to ongoing sea-level rise.

FIGURE 8-3-13. Photographs of the North Bluff Point site. **PANELS A and B.** Summer photographs looking northeast (A) across the Outfall Canal to the upland vegetation on the far spoil bank and looking southwest (B) along the outer edge of the marsh platform. The outer zone of this platform marsh consists of *Spartina alternaflora* that grades landward into a dense growth of *Spartina cynosuroides*. The latter grass is growing on a slightly elevated zone of spoil that was deposited along the outside of the impoundment ditch as indicated on Figure 8-3-13. Notice the highly irregular shoreline geometry of the rapidly eroding marsh peat shoreline. Photographs are by M. Murphy. **PANELS C and D.** Close-up photographs of the irregular marsh peat shoreline. The peat is about 6 to 7 feet thick at this point with the the wave-cut scarp eroded to depths of 2 to 4 feet below the water surface. Thus, the bottom of the estuary is still in the soft peat. The estuarine floor gently slopes away from the land to 6 to 7 feet water depth where the peat has been totally eroded away and the underlying tight clay forms the esturine floor. Notice the dark coffee color of the water.

FIGURE 8-3-14. The North Bluff Point site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1983 and 2000.

FIGURE 8-3-15. The North Bluff Point site aerial photograph time slices from 1983 and 1995. The rapid rate of shoreline recession is indicated by the red star. An entire segment of the marsh between Pamlico Sound and the outer ditch of the impoundment, southwest of Outfall Canal Road, has largely disappeared in this 12-year period.

FIGURE 8-3-16. The Swan Quarter site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1956 and 1998.

FIGURE 8-3-17. Photographs of the Lowland site. **PANEL A.** Winter photograph looking northeast within the cove and along a low sediment bank shoreline with *Spartina patens,* scrub-shrub, and pond pine growing on the upper surface. Notice the small strandplain beach that occurs only within the apex of the cove. **PANEL B.** Close-up of the wave-cut scarp eroded into the low sediment bank overlain by a thin pocosin peat containing a cover of *Spartina patens* in the foreground and pond pine with transition zone scrub-shrub in the background. The sediment bank is composed of a Pleistocene, tight, slightly sandy clay. This is the source of the limited sand forming the small strandplain beach in Panel A. Photograph is by M. Murphy. **PANEL C.** Summer photograph looking east along the narrow marsh platform in front of the mineral soils with their wetland woods consisting predominantly of scrub-shrub, bay trees, and pond pine. The marsh platform is composed of organic peat that is forming on top of and pinches out onto the mineral soil that forms the shoreline in Panel B. Photograph is by M. Murphy. **PANEL D.** Summer close-up of the marsh platform dominated by a narrow outer zone of *Spartina patens* adjacent to the water and an inner zone of *Spartina cynosuroides* that is growing on a very thin and slightly raised sand and wrack berm. Photograph is by M. Murphy. **PANEL E.** Winter photograph looking northwest along the marsh platform shoreline within the cove. Notice the thick roots of *Spartina cynosuroides* that extend out to edge of the eroding marsh peat where the plants have been stripped off by wave action. **PANEL F.** Close-up of the wave-cut scarp and wave-cut platform eroded into the marsh peat. In the foreground, the tight root-bound upper surface has been eroded off in a stair-step fashion, whereas, in the background, this root-bound surface is being undercut forming an overhang.

FIGURE 8-3-18. The Lowland site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1964 and 1998.

FIGURE 8-3-19. The Lowland site aerial photograph time slices from 1964, 1970, 1983, and 1995. The entire region within the area of the photograph is wetland. Dense scrub-shrub swampforest vegetation (red color in the 1983 photograph) lives in standing water on top of the tight clay soils much of the year. The slightly lower area surrounding and adjacent to the Oyster Creek drainage system is dominated by marsh grasses (light blue-green color in the 1983 photograph) living on a marsh peat substrate that thickens into the drainages. The time series suggests an expansion of the scrub-shrub swampforest vegetation through time (excluding the logged areas indicated with white stars) and loss of associated marsh along the Outer Pamlico River shoreline due to erosion (red stars).

FIGURE 8-4-1. Photographs of the Wades Point site. **PANEL A.** September 1979 photograph looking east towards the eroding Wades Point and a former beach cottage located on the nonhardened low sediment bank shoreline with upland pine vegetation. Photo is from Hardaway (1980). **PANEL B.** A January 2001 photograph from about the same location as Panel A. Notice the hardened shoreline, lack of upland vegetation, and a relatively new beach cottage. **PANEL C.** September 1979 photograph looking west along the low sediment bank shoreline of the Pamlico River. Photo is from Hardaway (1980). **PANEL D.** Close-up of the wave-cut platform eroded into the low sediment bank shoreline indicated in Panel E. The shoreline is composed of tight Pleistocene clay with the absence of a strandplain beach due to lack of sand in the eroding clay sediment. Also, the shallow root systems of the upland vegetation is totally excavated as demonstrated by the trees along the shoreline. **PANEL E.** January 2003 photograph looking north along the platform marsh shoreline of the Pungo River from Wades Point. The marsh interior is dominated by *Juncus roemarianus* with a narrow outer perimeter marsh dominated by *Spartina patens*. Locally, there is a narrow and mixed zone of *Phragmites australis* and *Spartina cynosuroides* that grow on a thin sand and wrack berm that parallels the shoreline. Notice the highly irregular erosion pattern of the marsh peat in the foreground and the upland area and associated low sediment bank shoreline in the distance (see Panel D). **PANEL F.** January 2003 close-up photograph of the eroding platform marsh shoreline. Notice the large peat block in the near shore that has recently broken off the shoreline.

FIGURE 8-4-2. The Wades Point site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1970, 1984, and 1998.

FIGURE 8-4-3. The Wades Point site aerial photograph time slices from 1970, 1984, 1989, and 2000. The rate of shoreline recession is obvious along the Pamlico River shoreline through time. Compare the fairly straight and unmodified shoreline and shore parallel Pamlico Beach Road in 1970 with the 2000 aerial photograph. Notice the sequence and effect of shoreline hardening upon the erosion process.

FIGURE 8-4-4. Photographs of the Hickory Point site. **PANEL A.** Oblique aerial photograph (December 1991) looking west across Indian Island and Hickory Point with Pamlico River to the right and South Creek to the left. Indian Island and Hickory Point are high areas along the interstream divide between the two water bodies. Indian Island has become separated from Hickory Point by rising sea level and associated shoreline erosion. **PANEL B.** Oblique aerial photograph (December 1991) of the study area at Hickory Point showing the marsh shoreline in the left foreground, modified low sediment bank shoreline along both sides of the Point, and unmodified low sediment bank shoreline along the wooded, curved coast in the upper left. **PANEL C.** A 1979 photograph along the South Creek low sediment bank shoreline prior to human modification. Notice the small pine stumps left in the near shore as the shoreline recedes and the beach cottage in the upper left corner that is collapsing into South Creek. Photograph is from Hardaway (1980). **PANEL D.** A 2001 photograph in approximately the same location as Panel C, showing the human modified low sediment bank shoreline. Notice that the rock and rubble revetment along the South Creek shoreline is slightly smaller scale than along the Pamlico River shoreline in Panel F. Photograph is from Murphy (2002). **PANEL E.** A 1979 photograph of a typical low sediment bank shoreline with a dense growth of small pine trees. The long pine tap root holds the stumps in place in the near shore as the shoreline recedes. Minor sand derived from the erosion of the Pleistocene, slightly sandy clay bank results in a thin and ephemeral strandplain beach. Photograph is from Hardaway (1980). **PANEL F.** A 2001 photograph looking west along the human modified, low sediment bank shoreline of the Pamlico River. Photograph is from Murphy (2002).

FIGURE 8-4-5. The Hickory Point and Pamlico Marine Lab sites 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1970, 1984, and 1998.

FIGURE 8-4-6. The Hickory Point and Pamlico Marine Lab site aerial photograph time slices for 1970, 1984, and 2000. The marsh shoreline on the South Creek side of Hickory Point has two small clumps of upland trees (dark zones) forming small headlands on the south side of the marsh in the 1970 aerial photograph. In the 2000 photograph these two areas of upland vegetation are completely eroded away and the shoreline is beginning to straighten out in response to the erosional processes. Notice the increased rate of shoreline hardening from 1970 to 1984 in concert with a significant recession of the unmodified low sediment bank shoreline west of Hickory Point along the Pamlico River shore (see Fig. 8-4-5).

FIGURE 8-4-7. Photographs of the Pamlico Marine Lab site. **PANELS A and B.** March 1978 close-up photographs of the unmodified and eroding low sediment bank shoreline of the Pamlico Marine Lab site. Panel A is on the western side and Panel B is on the eastern side of the lab. Notice the large trees lying along the bank and the stumps in the near shore, reflecting the receding shoreline. The area has been generally cleared for the lab, leaving only a few trees along the bank. **PANELS C and D.** August 2001 photographs of the modified low sediment bank shorelines of the Pamlico Marine Lab site. Panel C is on the western side and Panel D is on the eastern side of the lab. The rock revetment has temporarily stopped the shoreline recession. Photographs are from the pier by M. Murphy.

FIGURE 8-4-8. Photographs of the Bayview site. **PANEL A.** A September 1979 photograph looking at the eroding high sediment bank shoreline on the north side of the study site along outer Bath Creek. Notice the small strandplain beach due to the low sand content in the eroding bank, the overhanging modern root mass and tree roots, and the slumped trees. Photograph is from Hardaway (1980). **PANEL B.** A January 2001 photograph looking north along the same eroding high sediment bank as Panel A. It appears that there are far more stumps in the water and tree debris along the shoreline. **PANEL C.** An August 2001 photograph looking at the last remnants of the low sediment bank in front of an eroding high sediment bank shoreline in the middle of the study site. Photograph is by M. Murphy. **PANEL D.** An August 2001 close-up view of the eroding low sediment bank shoreline with a strandplain beach and fringing marsh in front of a stable high sediment bank with a heavy vegetative cover. Photograph is by M. Murphy. **PANEL E.** A September 1979 photograph looking south at the low sediment bank shoreline on the south side of the study site along outer Bath Creek. Notice the large number of trees standing in the near shore area with exposed roots. Photograph is from Hardaway (1980). **PANEL F.** A 2003 typical eroding low sediment bank along the open Pamlico River that is experiencing a more severe state of shoreline recession than the shoreline in Panel E. The sand strandplain beach is only a few inches thick and is on top of a Pleistocene, tight sandy clay substrate.

FIGURE 8-4-9. The Bayview site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1970 and 1998. Notice the small drainage system that flows west off the upland to form a small cypress headland in the middle of the study area.

FIGURE 8-4-10. Photographs of the Camp Leach site. **PANEL A.** A July 1977 photograph looking east along the undeveloped eastern portion of the study site on the Pamlico River north shore. The low sediment bank occurs behind an narrow zone of dense *Juncus roemerianus* and cypress growing on a peat substrate up to 2 feet thick. Photo is from Hardaway (1980). **PANEL B.** A January 1977 photograph looking west along a portion of the study site utilized by Camp Leach. Notice the *Juncus roemerianus* headlands with small coves containing thin strandplain beaches lapping up onto the low sediment banks. **PANEL C.** A January 1977 photograph of the low sediment bank shoreline in front of Camp Leach. Notice that the root system of the large shoreline trees have been severely exposed by the slow erosion processes. No marsh grass occurs within this high use area, however, there are local strandplain beaches scattered in the small coves along the shoreline. **PANEL D.** A January 2001 photograph in approximately the same area as Panel C. The low sediment bank in this development has now been extensively bulkheaded with the elimination of marsh headlands and shoreline trees. Notice that no strandplain beaches exists in front of bulkheads.

FIGURE 8-4-11. The Camp Leach site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1970 and 1998.

FIGURE 8-4-12. Photographs of the Mauls Point site. **PANEL A.** A July 1977 photograph looking southwest along the unmodified bluff at Mauls Point. Notice the overhanging modern root mass, the tree debris along the shoreline, and the strandplain beach in front of the wave-cut bluff. Photograph is from Hardaway (1980). **PANEL B.** A August 1998 photograph of the bulldozed and bulkheaded bluff that occurs in Panel A. A portion of the modified bluff has been seeded and covered with landscape fabric. **PANEL C.** An August 2001 close-up photograph of the modified bluff pictured in both Panels A and B. Notice the lack of a strandplain beach in front of the steel bulkhead and rock revetment. Photograph is from Murphy (2002). **PANEL D.** A January 2003 photograph of the modified cypress headland that occurs off of a small drainage system dissecting the upland and associated bluff on the southwest side of the study site (see Fig. 8-4-14). The local occurrence of sand in front of the bulkhead that formed in response to a bulkhead failure and associated gullying just below the bottom of the photograph. **PANEL E.** A 1979 photograph of the swampforest shoreline along the cypress headland that occurs at Mauls Point, on the northeast side of the study site. Photograph is by S. Hardaway. **PANEL F.** An August 2001 photograph of the same location as Panel E. The rock is the northeast end of the revetment in Panel C. Notice how the swampforest has been thinned and the occurrence of a small strandplain beach that used to be located in front of the bluff. Photograph is from Murphy (2002).

FIGURE 8-4-13. The Mauls Point site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1970, 1984, and 1998.

FIGURE 8-4-14. The Mauls Point site aerial photograph time slices from 1984 and 2000. Mauls Point Road runs north along an interstream high between two small drainages that parallel the road. The drainage on the northeast side of the road has been intersected by the Pamlico River creating a wide swampforest shoreline along the Pamlico River side and forms a cypress headland at Mauls Point (Fig. 8-4-12, Panels E and F). The bluff shoreline occurs where Blounts Bay intersects the interstream divide at the end of the road (Fig. 8-4-12, Panels A, B, and C). Another small swampforest shoreline forms a cypress headland that extends into the water where the drainage on the southwest side of the road flows into Blounts Bay (Fig. 8-4-12, Panel D).

FIGURE 8-4-15. Photographs of the Bay Hills site. **PANEL A.** A July 1977 photograph looking east along a highly vegetated, natural bluff shoreline. The lack of an erosional cut-bank, slump blocks, and tree and shrub debris indicate that this bluff is not eroding on the year-to-year scale. This moderately stable bluff shoreline has a modest slope that can develop a significant vegetative cover that protects the bluff through the small storms and the short term. Photograph is by S. Hardaway. **PANEL B.** A January 2003 photograph along the same portion of the Bay Hills that locally displays steeper erosional bluff segments and wider strandplain beaches with abundant tree debris. Portions of this shoreline were locally destabilized by a series of very high storm tides (up to +10 feet above mean sea level) that impacted the upper Pamlico River area between 1996 and 1999. Thus, normally stable shorelines in semi-protected areas and estuarine segments with small fetches, do erode, but mainly during extreme storm events when the shoreline recedes in large pulses. **PANELS C, D, and E.** Panel C is a January 1977 photograph looking west along a modified bluff shoreline. The bluff was bulldozed in 1975 to form a 1:1 sloped ramp behind a low sediment bank shoreline. Both the bulldozed bluff and low sediment bank have, in most cases, been extensively bulkheaded as demonstrated in the 2001 photographs in Panels D and E. Much of this extreme bulkheading was done since the high storm tides of the 1996-1999 hurricanes destabilized and severely eroded the bluffs. Notice that the natural bluff shoreline in Panel D still has a strandplain beach. Photograph in Panel D is from Murphy (2002) and Panel E is by M. Murphy. **PANELS E and F.** Panel E is a close-up view of the Pleistocene, tight blue clay that crops out along the lower fifteen feet of the bluff shoreline. An easily erodable, unconsolidated sand bed overlies the clay bed. The former readily slumps onto the beach carrying the vegetative cover with it, as demonstrated in Panel F. This stratigraphic combination produces bluffs with an overall lower slope that can generally develop more stable vegetative covers. Photographs are from Murphy (2002).

FIGURE 8-4-16. The Bay Hills site 1998 Digital Orthophoto Quarter Quadrangle (DOQQ) with digitized shorelines for 1970 and 1998.

FIGURE 8-4-17. The Bay Hills site aerial photograph time slices from 1938 and 1984. Compare the absence of waterfront cottages in the 1938 aerial photograph with the high density of homes with associated piers extending into Chocowinity Bay in the 1984 photograph. Notice the small drainage system just west of Bay Hills Drive in the 1984 photo. Where this stream enters Chocowinity Bay, the cypress trees in the floodplain swampforest form a cypress headland. Cypress headlands are more resistant to shoreline erosion then adjacent sediment banks and therefore protrude out into the Bay, while the sediment banks erode slightly faster and form shallow coves.