Overview of Oceanfront Shorelines: Cape Lookout to Sunset Beach, NC

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NORTH CAROLINA COASTAL SETTING

A map of the NC coastal system reflects major differences in the geological heritage derived from the underlying geological framework (Riggs et al., 1995). Cape Lookout separates the 336 mile long coastline into two distinct provinces (Fig. 1). Each province has a unique geologic framework that results in distinctive types of coastal features. The northern province is underlain primarily by unconsolidated sediments of Quaternary age that thicken northward to fill the Albemarle Embayment with up to 230 ft of material. The low-lying coastal area that has evolved along this gentle depositional surface consists of wide shallow bays fronted by long narrow barriers. A few hardbottoms of Pleistocene age are found scattered across the shoreface (Riggs et al., 1992, 1995; Boss and Hoffman, 1999).

In contrast, the coastal system in the southern province, from Cape Lookout (Figs. 1 and 2) south to the South Carolina border, is underlain by rock units that range in age from the Upper Cretaceous through the Pleistocene (Meisburger, 1977 and 1979; Snyder et al., 1982; Snyder et al., 1994 and Cleary et al., 1996). In this region, only a thin and highly variable veneer of sediments of Quaternary age is preserved. The underlying units are associated with the Carolina Platform that underlies the region between Myrtle Beach, SC and Cape Fear, NC. This structural platform has risen slightly causing the units to dip to the north and east, causing them to be truncated by the shoreline and the shoreface. Consequently, a steep erosional topography exists along the southern coastal system with common exposures of these Cretaceous to Quaternary age units across the shoreface (Riggs et al., 1995).

Coastlines with limited sand supplies, such as most of the North Carolina system, have thin barriers resting atop older geologic units that constitute the shoreface (Davis and Kuhn, 1985; Cleary and Hosier 1987; Riggs, et al., 1995). Other than the sand rich barriers (former progradational barriers) near Bogue Banks (Fig. 3), perched barriers are common along the coastline of southeastern North Carolina and consist of a thin layer of sand that occurs directly on top of a shoreface extension composed of older, eroding, geologic units (Riggs et al., 1995; Thieler et al., 1995 and 2001). Depending upon the composition and geometry, this underlying platform can act as a headland strongly influencing the beach dynamics and sediment composition, as well as the shape of the shoreface. In addition, along many parts of the coast, erosion resistant rocks that occur in the shoreface form shoal features that affect the local shoreline change patterns and sediment transport. The complex variability in this underlying geologic framework, coupled with the physical dynamics of a specific setting, ultimately determines the: 1) three-dimensional shoreface geometry, 2) availability and composition of sediments, and 3) shoreline erosion rates.

Dissecting the underlying geologic units is a paleo-drainage system consisting of a series of major and minor stream valleys and adjacent inter-stream divides (Riggs et al., 1995). This drainage system controls the large-scale topography and forms a series of non-headland and headland influenced segments of the coast. The coastal features are perched on top of this framework which controls the overall geometry as well as the availability of sand resources.

Headland dominated shorefaces are areas that occur on topographically high inter-stream features composed of semi-indurated sediments and rocks of older geologic units (Morefield, 1978; Riggs et al., 1995; Marcy and Cleary, 1998, Marden and Cleary, 1999). These features may crop out on the subaerial beach such as the Quaternary sequences along the isolated locales on Masonboro Island, Carolina Beach/Fort Fisher and Yaupon Beach along Oak Island (Fig.1). More commonly, the rocks occur as submarine features where they crop out on the shoreface such as the submarine headland along portions of North Topsail Beach and nearby Onslow

Beach. In this area Oligocene age limestones form high-relief hardbottoms immediately seaward of the recreational beach (Crowson, 1980; Cleary and Hosier, 1987; Riggs et al., 1995; Cleary et al., 1996; Johnston, 1998; Cleary and Riggs, 1998 and Cleary et al., 1999). These rocks extend beneath portions of North Topsail and Onslow Beaches affecting both their palnform, rates of erosion, and sediment supply.

Non-headland dominated shorefaces are the most common type along southeastern North Carolina's coastal system. These shorefaces are generally composed of one of four different kinds of sediment components: valley-fill, inlet-fill, transgressive, or regressive coastal lihosomes. The barrier segments that flank the Yaupon Beach headland segment of Oak Island and the southern portion of North Topsail Beach are examples of transgressive segments. Examples of regressive shoreline reaches that are usually sand rich include major portions of Bogue Banks and adjacent Bear and Browns Islands (Figs. 1 and 3).

Southeastern North Carolina Shoreline Overview

As mentioned Cape Lookout forms a natural division of the North Carolina coastline. North of this Cape, the islands are separated from the mainland by relatively wide open water estuaries contrasting with the southern system where the estuaries are narrow and nearly filled with marsh. The 17 barriers that comprise the 155 mile long coastline between Cape Lookout and Little River, SC have a wide variety of morphologic forms, ranging from overwash-dominated narrow barriers to wide barriers with massive dunes and no washovers (Figs. 3 and 4). The approximate division between the two morphologic classes occurs between Browns Island and Onslow Beach (Fig. 1). In this area a submarine headland composed of Tertiary limestone, forms a small bulge in the coastline that separates the relatively stable, formerly regressive barriers that are sand rich to the northeast from the transgressive eroding sand poor barriers to the southwest (Figs. 2 and 3). At Fort Fisher/Kure Beach, a subaerial headland composed of Plesistocene sandstones and coquina forms the southern boundary of the transgressive barrier segment. A narrow spit extends southward from the headland to the Cape Fear Foreland (Fig. 1). In adjacent Long Bay immediately west of the Cape Fear River is a small subaerial headland at Yaupon Beach composed of the same Pleistocene units found at Fort Fisher/Kure Beach.

Fisher/Kure Beach. Flanking the headland are two transgressive spits that extend toward the adjacent inlets. The westward extending spit (Long Beach) and three additional composite barriers extend toward the NC/SC border at Little River (Fig. 1).

The longest of the barriers in southeastern North Carolina is Bogue Banks, 25.4 miles long; Hutaff Island is currently the shortest barrier in the chain ~3.2 miles long. Bar-built estuaries are widest in the north, behind Bogue Banks, and generally decrease or finally disappear where the islands have overridden headlands. The northern estuaries, principally Bogue Sound, are largely shallow, generally open, and free of vegetation. By contrast, tidal marshes generally have infilled the southern estuaries primarily due to the influence of migrating tidal inlets. Elevations on the islands range from less than 3 ft in some places on Masonboro Island to more than 50 ft above MSL on Bear Island. Inlets vary from wide, deep, stabilized and maintained inlets such as Beaufort Inlet (Fig. 1), separating Bogue and Shackleford Banks, to narrow, shallow, shifting inlets such as Mason's (Fig. 1), separating Shell Island and Figure Eight Islands. Human impacts on the islands vary from extensive development on Wrightsville Beach, Bogue Banks, and Topsail Island to uninhabited islands such as Hutaff and Bear Islands.

The following sections of this report provide a brief overview of each of the barriers and shoreline segments that comprise the study area. Emphasis is placed upon the developed shoreline reaches.

Shoreline Overview

Shackleford Banks

Shackleford Bank is a 9.5 mile long east-west trending island separated from Cape Lookout by Barden Inlet (Fig. 5 A and B). In 1933 a severe hurricane opened Barden Inlet separating the barrier from the Cape Lookout foreland and Core Banks (Figs. 1 and 5 A and D). Core Banks and Shackleford Bank are part of the Cape Lookout National Seashore. Before the turn of the 20th century, Shackleford Bank was fully forested. A series of dune ridges indicating previous progradation was evident. Much of the barrier was probably similar to Bogue Banks. A combination of severe hurricanes, overgrazing by feral livestock, and anthropogenic disturbance of the forest resulted in the destruction of the vegetation mantle in the late 1800's and the subsequent migration of the dunes across the island. A 3.2 mile long slipface marks the landward migration limit of the dunes. Beaufort Inlet, a large stable inlet borders the western end of Shackleford Bank (Figs. 5 and 6 B-C) that has been growing westward during the past 40 years. Since 1947, the island has extended more than 3,000 ft. This region is characterized by low dunes generally in an arcuate pattern (Fig. 6).

Bogue Banks

Bogue Banks is the longest and widest barrier island in SE NC (Figs. 1 and 7). This composite and former progradational barrier is ~ 25.4 miles long and averages 1,970 ft in width. Unlike the areas to the south, the estuary behind Bogue Banks is generally open water (Fig. 7A-D). The lack of significant areas of tidal marsh suggests that inlets have not been active on an island scale in recent historic times. However, historic maps show isolated occurrences of former inlets at several sites. These areas include the low, narrow sites at Emerald Isle and at Atlantic Beach.

Bogue Banks, located on the low energy limb of the Cape Lookout foreland, is morphologically unlike the majority of islands in North Carolina (Fig. 1). It is characterized by an extensive forested dune ridge system with isolated ridge elevations in excess of 39 ft (Fig. 7A-D). This sequence of ancient dune ridges indicates a period of progradation. Recent studies indicate progradation began 3800 years B.P. (Steele, 1980; Heron, et al., 1984). The details of the evolution of the barrier are beyond the scope of this report. However it is worthwhile to mention that the barrier is a composite of different “core-segments” that are of different ages and origins.

The island's fronting dune system is largely intact. Multiple or massive dunes are characteristic. Within these areas are sites of blowouts and migrating and vegetated parabolic dunes. The initiation of these features was presumably due to fires, storms, and man, all of which destroyed the binding vegetation and promoted the remobilization of the sand (Fig. 7 A, C-D). A few areas have a narrow dune system. Overwash is not an important environmental parameter except in those areas where dunes are lacking or poorly developed. The sheltering effect of Cape Lookout, the island's east-west orientation and the barriers elevation are factors responsible for the lack of significant oceanic overwash (Cleary and Hosier, 1979 and Cleary and Pilkey, 1996) .

Beaufort Inlet located approximately 9 miles west of Cape Lookout serves as the connection between the Atlantic Ocean and Morehead City Harbor, North Carolina’s second major port (Fig. 6 A). The inlet is utilized by commercial and recreational vessels and is one of two inlets in southeastern North Carolina which have been modified for commercial traffic. The inlet forms the eastern border of Bogue Banks and separates the barrier from Shackelford Banks to the east (Fig. 6 A-D).

Historic maps that date to the early part of the seventeenth century confirm the existence of the inlet. Since the Colonial Period the inlet has served as an entry to the port of Beaufort. Beaufort Inlet has remained in relatively the same location throughout its recorded history. The large tidal prism contributes to the stability of the inlet. Over the past 70 years, since the channel has been in a fixed position (1936), the inlet’s cross-sectional area has fluctuated little although the inlet’s minimum width has decreased (Cleary and Pilkey, 1996). During the same period, the average depth of the throat has increased as the navigation channel was deepened and widened. As a result the inlet’s aspect ratio (w/d) has decreased markedly since 1952 as the inlet constricted and deepened with dredging. Since dredging of the channel began, there has been a deepening and steepening of the profile and a generally lowering of the ebb-tidal delta platform.

Calculations involving changes in the volume of sediment stored in the 1854 ebb-tidal delta, indicated there was 48.97 million cy of material contained in the outer bar to depths of ~18 ft. Between 1854 and 1936, the ebb delta volume ranged from a low of 46.69 to a high of 56.63 million cy in 1874 (Cleary and Pilkey, 1996). Since major dredging operations began in the mid 1930’s the volume of the ebb-tidal delta has steadily decreased from 48.26 million cy in 1936 to 31.65 million cy in 1974, a 34.2 % loss. Between 1974 and 2004 the outer bar volume has further decreased to 21.12 million cy. The net volume loss since 1936 was 27.14 million cy to depths of -18 ft. The most significant loss occurred within the Bogue Banks segment of the shoals on the western margin of the ebb channel. The reader is referred to a report by Olsen and

Associates (2006) that details the losses within the Beaufort Inlet system and the impact on the Bogue Banks oceanfront.

Between 1936 and 2004 as much as 70 million cy of material have been dredged during the periodic maintenance of Beaufort Inlet. According to Olsen and Associates (2006) 13.8 million cy of material derived from the Morehead City Harbor Project have been placed along the Bogue Banks oceanfront between 1978 and 2004. Since 2004 a minimum of an additional 3.0 million cy (estimated) have been placed along the oceanfront. Most of the material was derived from the harbor project. It is beyond the scope of this overview to present a detailed discussion of the causes of the erosion along Bogue Banks but it is suffice to mention that the depleted ebb-tidal plays a significant role. The reader is referred to the aforementioned report by Olsen and Associates (2006) and the various USACE reports dealing with the Morehead City Harbor Project and related projects.

Bogue Inlet is one of the larger inlets in southeastern North Carolina (Fig. 7 C-D) and separates Bogue Banks and Bear Island (Hammocks Beach). The inlet drains an expansive portion of the adjacent estuary where two large, relatively deep tidal creeks connect the inlet to the AIWW and the White Oak River Basin (Fig. 4 A). The inlet has been a relatively stable feature over the past several centuries and has been confined to a 2,625 ft wide zone. Seismic studies of the shoreface indicate that the inlet is a "permanent" feature in the area, its location initially controlled by the paleo-channel of the White Oak River which extends across the shoreface (Hine and Snyder, 1985). The inlet has an exceptionally wide throat ~8,500 ft, a relatively narrow ebb channel ~700 ft and a large mid inlet shoal that occupies most of the western portion of the floodway (Cleary, 1996; Cleary and Marden 1999; CS & E, 2001; Cleary et al., 2003). The ebb channel is unstable and has a history of migration related to spit growth on opposing shoulders. The ebb channel began its recent eastward trek in 1981/82 while the outer bar segment of the channel was skewed toward Bear Island (Cleary, et al., 2003). Between 1981 and 2001, the throat section of the channel migrated to the east a net distance of 4,013 ft at an average rate of 201 ft/yr.

Chronic erosion along the western end of Bogue Banks (Emerald Isle) reached a critical stage in the late 1990s when a number of homes were endangered by the receding inlet shoreline. Subsequent to onset of the rapid loss the shoreline was armored with a series of sandbags. The Town was also experiencing erosion along much of its oceanfront; and as a result, it initiated an extensive 16.8 miles long nourishment project. In an effort to support shoreline restoration and to provide a long-term solution to inlet-related erosion the Town contracted with Coastal Planning & Engineering (CPE-NC) to relocate the ebb channel to a mid inlet position and nourish a portion of the oceanfront with the associated dredge materials (Fig. 7 D).

The analysis of the oceanfront and shoulder changes that occurred since 1973, clearly showed that the movement of the ebb channel and the attendant ebb-tidal delta symmetry changes were the forcing variables that dictated the change trends along the inlet and oceanfront of both Bogue Banks and Bear Island. Erosion of the eastern inlet shoreline (Bogue Banks) and the progradation of the adjacent oceanfront were directly related to the eastward migration of the ebb channel. The data also indicated that the inlet and oceanfront erosion along adjacent Bear Island stemmed directly from the morphologic changes related to the eastward migration and the associated ebb shoal shape changes. The data and a simple visual inspection of the aerial photographs suggested there was a felicitous inlet (ebb channel) configuration that provided mutual benefits for both shoulders and oceanfront shoreline segments that flank the inlet. The channel relocation site is located within this optimum zone.

The location of the ebb channel lies along the approximate axial position of the ebb channel imaged on the 1978 aerial photograph. Relocation of the ebb channel in early 2005 to this mid inlet location has altered the sediment transport patterns on both shoulders and prompted a significant reconfiguration of the ebb-tidal delta. The apex of the ebb delta is in the process of shifting westward. The eastern ebb shoal segment fronting Bogue Banks is gradually collapsing and will eventually infill the former ebb channel. In September 2005 Hurricane Ophelia breached the Bogue Banks estuarine spit that led to a connection between the former ebb channel and interior tidal channels. This event eroded the dike that was constructed to hasten the closure of the old channel and in effect lengthened the time for complete infilling and abandonment of the former ebb channel (Fig. 7 D). The eventual infilling of the former ebb channel will lead to westward growth of Bogue Banks and planform changes along the oceanfront.

The geology and nature of Bogue Banks and the adjacent shoreface have been investigated by a number of researchers including Fisher (1967), Mixon and Pilkey (1976), Meisburger (1979), Steele (1980), Riggs, et al., (1982), Snyder (1982), Snyder et al., (1982), Heron, et al., (1984) and Hine and Snyder (1985). Most of Bogue Banks is underlain by the Miocene, Pungo River Fm much of which consists of muddy, phosphatic sand and silt (Fig. 2). Hine and Synder (1985) indicated that Holocene units were thin (3-7 ft) and often absent on the shoreface and inner shelf in the region. Consequently, Miocene age rocks are often exposed particularly off the east and central portions of Bogue Banks.

Seismic and limited core data (Hine and Snyder, 1985) revealed the existence of a number of paleo- channels that were infilled with mid Pleistocene deposits. The former and now buried, lower coastal plain stream channels were interpreted to be infilled with a relatively thick sequence consisting of estuarine and shelf muds and sands. Other smaller localized channels recognized in seismic records were interpreted to the vestiges of the deeper portions of tidal inlets. It has been postulated that the larger paleo-channels have been major sources of sand for the initial development of the wider and higher regressive portions of Bogue Banks (Snyder, Personal communication, 1994 and more recently by Rodriguez, 2008). This hypothesis is similar to the speculation that the segments now characterized by large parabolic dunes along the composite barriers in Brunswick County initially derived their material from the numerous, now closed tidal inlets, and the offshore sand associated with the major coastal plain streams in the area.

If the larger buried channels off Bogue Banks are proven to contain compatible fill material they surely will be targeted as potential borrow sites that can be readily utilized for future large- scale nourishment operations due to their proximity to the oceanfront. It is interesting to note that the only paleo-channels that have been proven to contain quality material are those associated with the paleo-channel complex of the Cape Fear River off the Forth Fisher-

Carolina Beach headland segment. Coring of smaller channel features associated with small incised coastal plain creeks that exist between New River Inlet and Carolina Beach showed that all were filled with thick Holocene estuarine mud and muddy sand.

Bear and Browns Islands

Bear and Brown Islands are 3.3 and 3.9 miles long, respectively. They average 1,970 ft in width. They can be classified as altered regressive (prograded dune ridge) barriers (Figs. 4 and 8). Large medano-like and parabolic dunes characterize major portions of both islands. The earliest aerial photographs (1938) show the majority of both island surfaces were covered by large sand sheets with little vegetation cover (Cleary and Hosier, 1979 and Cleary and Pilkey, 1996). The existence of large steep spillover lobes in the adjacent estuary provides evidence for the landward migration of the sand dunes (Fig. 8). Elevations along the eastern portions of the barriers are as much as 52 ft. The nature of the dunes imaged in the 1938 photographs is similar to the migrating parabolic dunes found along all of the Brunswick County barriers in the 1930s and 1940s. The sand that formed the various migrating dune types on Bear and Brown's Islands was thought to have been originally contained in sets of prograded dune ridges similar to what is found on Bogue Banks.

The enormous volume of sand found within these short, wide and high barriers is unique and more than likely represents the type of short barrier reaches that formed the prograded core segments of ancestral composite Bogue Banks that initially consisted of multiple islands separated by wide shallow inlets. The large volumes of sand contained in these barriers were derived from sand-rich Silverdale Fm that is exposed on the shoreface (Riggs and Cleary, 1998a ,1998b and Cleary and Riggs, 1998). The contact between the Silverdale Fm and the Belgrade Fm (bio-modic limestone) is located near Brown's Inlet. Southwest of Brown's Inlet the narrow, sand poor barriers are perched on limestone (Fig. 2).

Onslow Beach

In the vicinity of New River Inlet (Fig. 1) is a submarine headland that forms a small seaward bulge in the coastline of central Onslow Bay (Fig. 1). This mid compartment shoreline protrusion is produced by the Oligocene Belgrade Fm, a bio-moldic limestone. The unit crops out at or slightly below sea level in the mouth of the New River estuary. It occurs extensively on dredge spoil islands of the Intracoastal Waterway behind Topsail Island and Onslow Beach, and forms a series of high ridges on the shoreface off of New River Inlet (Crowson, 1980; Cleary and Hosier, 1987; Riggs et al., 1995; Cleary et al., 1996; Johnston, 1997 and Cleary and Riggs, 1999).

The submarine headland subdivides these two barriers into coastal compartments that have different orientations and shoreface dynamics. The northern segment of Onslow Beach is characterized by a shoreline reach with a wide beach, a recurved, accretionary dune ridge system and a continuous high foredune ridge (Cleary and Hosier, 1987 and Cleary and Riggs 1998). The ridges front a narrow marsh filled estuary and are covered with mature maritime forest indicating old and stable topography (Figs. 8 A-D and 9 A-C). Toward the central portion of Onslow Beach, the estuary along the northern and southern segments narrows and is nearly absent where the limestone comprising the headland rises close to the surface. At the narrowest width of the estuary (Fig. 9 B-C) the limestone lies within six feet of the surface of the fringing marsh (Cleary and Hosier, 1987; Riggs et al., 1995; Cleary and Pilkey, 1996; Cleary et al., 1996 and Cleary and Riggs, 1998).

The southern segment of Onslow Beach is characterized by a narrow beach strewn with gravel, isolated “haystack” dunes with numerous washover passes and terraces extending into the marsh (Fig. 9 A-C). The structure of the remaining dune field is largely a result of the damage caused by the numerous maneuvers and operations of the U.S. Marine Corps. Staging and landing operations involving US Marines and heavy equipment including tanks and large “air-boats” have been carried out for decades. The highest erosion rates characterize the area immediately updrift of New River Inlet. The southernmost portion of the barrier is currently undergoing very rapid erosion (Fig. 9 D). Changes in the New River Inlet system since the 1940s are primarily responsible for the shoreline retreat (Cleary et al., 2003). The reader is referred to a more detailed report of the inlet contained in a subsequent section of this document.

Topsail Island

Topsail Island is the second longest (24 mi) barrier island within Onslow Bay. The island is bordered by the New River Inlet to the north and New Topsail Inlet to the south (Figs. 1 and 10). The Towns of North Topsail Beach, Surf City and Topsail Beach comprise the developed section of the barrier. Despite the low, long-term erosion rates the majority of the infrastructure along Topsail Island is highly vulnerable to storms. Inspection of historic photographs shows that much of the barrier is a chronic overwash zone. As a consequence the towns have requested assistance to nourish the entirety of the oceanfront. The reader is referred to four reports dealing with detailed discussions of the New River and New Topsail Inlets as well as the North Topsail Beach/Surft City and the Topsail Beach shoreface in subsequent sections of this document.

Hutaff Island

Hutaff Island is 3.7 mile long transgressive barrier located in southwestern Onslow Bay. The washover-dominated barrier is bordered by New Topsail Inlet to the northeast and Rich Inlet to the southwest (Fig. 11). The undeveloped barrier is now comprised of Lea and Hutaff Islands that were joined subsequent to the closure of Old Topsail Inlet in June 1998 (Fig. 11). Historically the barrier has been influenced by at least four inlets that have contributed to the infilling of the estuary. The most noteworthy changes along Hutaff Island since 1938 were the results of the southwest migration of Old Topsail and New Topsail Inlets. The former Hutaff and Lea Island barrier segments were considerably shortened as a result of the inlets' migration.

Severe storm events have frequently impacted the barrier resulting in dramatic erosion and overtopping of the island (Fig. 11). The development of major washover terraces coupled with storm-induced erosion has dramatically lowered the barrier's vertical profile. Consequently, the island is poised to migrate landward at accelerated rates during future storm events. Since 1938 the island has retreated as much as 490 ft. Long-term shoreline erosion rates average 7.0 ft/yr (McGinnis, 2004; Doughty et al., 2006).

The shoreface that fronts the barrier consists of a thin veneer of sand and gravelly sand. The mobile surface veneer is generally less than three feet thick and overlies an easily eroded

Oligocene siltstone unit that frequently crops out on the shoreface forming low-relief hardbottom areas. Mud-filled paleo-fluvial channels, the seaward extensions of the local major tidal creek systems were identified on the shoreface.

Figure Eight Island

Figure Eight Island is a narrow 4.6 long island separated from Hutaff Island by Rich's Inlet and from Wrightsville Beach/Shell Island by Mason's Inlet (Fig. 12 A and B). The private residential island exhibits two distinct physiographic segments. The entire barrier is underlain by inlet fill. The southern portion of the barrier is a washover-prone spit that extended southward subsequent to the opening of Mason Inlet, a migrating inlet, in 1880. The northern older segment of the island is narrow and in places the core of the barrier is forested. Toward Rich Inlet the barrier is offset seaward due to the inlet-related accretion zone. The historic accretion zone consists of a series of parallel dune ridges that developed since the 1890s. This zone periodically erodes or accretes as the alignment of the ebb channel changes. Rich's Inlet has shown little tendency to migrate, however, the cyclical re-orientation of the ebb channel can produce very rapid erosion on the downdrift shoreline (Fig. 12 A insert). Since 2002 a number of homes along the impacted shoreline are fronted by a series of sandbags (Cleary et al., 2002and Jackson and Cleary, 2006).

Since the island is privately owned, the landowners themselves are responsible for maintenance of the oceanfront beach. Several renourishment projects have attempted to mitigate the chronic erosion. The island has an evolving management plan in place involving the beach and adjacent inlets.

Wrightsville Beach and Shell Island

Wrightsville Beach is a 5.0 mile long transgressive barrier (Fig. 13). Because of its proximity to the city of Wilmington, it was one of the first barrier islands in North Carolina to be developed as a resort. Bath houses and summer cottages built in the 1860's were serviced by a trolley line that was completed in 1889. This railroad ran a distance of ~7 miles from

Wilmington across the sound to the beach and the seven trolley stations. Early photographs (1915-1925) show that the northern portions of Wrightsville Beach had large elevated dunes and a wide island profile. To the south the island was very narrow and low. In order to create more elevated land, Waynick Boulevard, the road parallel to Banks Channel, was constructed with dredge material and built over tidal marsh in the 1930's (Cleary and Hosier, 1977 and Cleary and Pilkey, 1996).

Erosion on Wrightsville Beach is chronic issue. From the earliest attempts at building along the oceanfront, erosion problems have existed. For example, between 1923 and 1939, more than two dozen concrete and timber groins were emplaced along the shoreline in an attempt to mitigate erosion. The first attempt at replenishing the sand lost to erosion occurred in 1939 (US Army Corps of Engineers, 1982). Between 1944 and 1965, four major hurricanes (including Hurricane Hazel, 1954) and a number of winter nor'easters resulted in significant shorefront erosion. In 1965, the Wrightsville Beach Erosion Control and Hurricane Protection Project was constructed along 2.8 miles of oceanfront which extended north from the Masonboro Inlet north jetty (Figs.13 and 14) to the town's northern limit (Cleary and Hosier, 1977 and Cleary and Pilkey, 1996).

Additional sand was pumped on the shore to close Moore's Inlet, located 0.28 miles north of the town. In all, a total of 2,979,960 million cy of fill was placed on Wrightsville Beach. Subsequently, the town annexed the 0.47 mile section north of its original corporate limits which included Moore's Inlet. Between 1938 and 1965, Moore's Inlet migrated along the above mentioned barrier segment of Wrightsville Beach and adjacent Shell Island. Historic aerial photographs, maps, and charts show the inlet affected the shape of the adjacent oceanfront by producing a convex shoreline protuberance (shoreline which curves seaward) immediately adjacent to the inlet (Fig. 13 B-C and 14 B).

Following the artificial closure of Moore's Inlet (1965), the building line and roads along the new northern corporate limits were extended and paralleled the pre-closure curved shoreline. Much of the erosion along the restored northern part of Wrightsville Beach stems from a natural attempt to eliminate the “bump” and restore an equilibrium planform consisting of smoothed shoreline (Figs. 13 B and 14 B). Evidence for rapid erosion along the newly annexed portion of Wrightsville Beach fronting Moore's Inlet was obvious by the late 1960's. This recession necessitated the placement of additional of sand along the oceanfront. By the middle 1970's, homes and structures along the northern flanks of the bulge were fronted by bulkheads and walls of protective rip-rap. Additional restoration in 1980 and 1981 placed 1,794,000 cy of fill along the northern 1.52 miles of the oceanfront, temporarily reversing the shoreline retreat. In 1986, an additional 871,000 cy of material was placed along the erosion hot-spot. US Army Corps of Engineers estimated that the convex shape of the shoreline accelerates the annual erosion of the fill by ~ 32% (Jarrett, 1977; US Army Corps of Engineers, 1982). Since the mid 1990s at least three additional beachfill operations have occurred.

The hurricanes of the 1990s (Bertha 8/96, Fran 9/96, Bonnie 8/98 and Floyd 9/99) produced significant overwash and limited structural damage (Cleary, 1999 and 2000) within the chronic erosion zone that developed along the mid barrier shoreline bulge (Fig. 13 B-C). By comparison other sections of Wrightsville Beach located south of Mercer's Pier and the shoreline bulge were impacted only slightly. Overwash and erosion was limited and minor along almost the entire southern section of the beach. Similarly along the shoreline reach north of old Moore's Inlet, dune erosion occurred but overwash for the most part was restricted to the breaks within the foredune. Little structural damage occurred along the northern part of Wrightsville Beach (Shell Island).

Wrightsville Beach is one of the most-replenished beaches on the U.S. East Coast (Pilkey and Clayton, 1987 and 1989), and has been funded under the widest variety of federal authorizations of any beach in the U.S. (Pilkey and Clayton, 1987). Major replenishments have been carried out at approximately four-year intervals since 1965, each of which involved the placement of fill material dredged from the interior channels and portions of Masonboro Inlet (Fig. 13 A).

Investigations of the shoreface off Wightsville Beach in the 1990s showed that the shoreface sediment cover off Wrightsville Beach is a patchy, relatively thin veneer blanketing low-relief, Tertiary limestone and silstone. The modern sediment averages ~ one foot in thickness. The primary underlying units are a Plio-Pleistocene limestone, an unconsolidated Oligocene siltstone, and Quaternary mud and muddy sand within incised paleo- fluvial channels (Snyder et al.,. 1994; Thieler, et al., 1995and 2001). Since the shoreface sand resource potential is very low, future USACE beach replenishment projects will continue to rely on the beach fill quality material dredged from the interior feeder channels for Masonboro Inlet and possibly the fillet on the southern margin of Masonboro Inlet (Fig. 13 D).

Mason Inlet located at the north end of Shell Island separates Figure Eight Island a private residential Island from Wrightsville Beach a public accessible barrier (Figs. 15 and 16). This relatively small inlet was the focal point of a number of management and regulatory issues during the period since the mid 1990s. The issues were related to the inlet related erosion hot-spots on both the updrift and downdrift oceanfronts, deterioration of the soundside channels, navigation improvements, armoring of the Shell Island inlet channel bank and the potential closure of the inlet. Historical studies of Mason Inlet documented its opening in the late 1880's and its subsequent southerly migration (Cleary and Hosier, 1979; Brooks, 1988; Cleary and Marden, 1999; and Johnsen, et al., 1999 and Freeman, 2001). The rate of inlet migration has varied by an order of magnitude over decadal scales and there have been minor short-term reversals in the direction of migration. During the period between 1974 and 1997 the inlet migrated southward 3,610 ft at an average rate of ~ 160 ft/yr. Rates over this time interval ranged from 3 - 295 ft/yr with the highest rates coinciding with overall shoaling of the inlet. In 1997 the Shell Island inlet margin was armored with oversized sandbags to protect infrastructure and the former Shell Island Resort complex (Fig. 15).

Subsequent studies (Freeman, 2001) and land surveys (ATM 2000, 2001) indicated that stabilization of the inlet led to a narrowing and slight deepening of the channel. Between 1996 and 1999 the southerly longshore transport and accompanying growth of the spit/spit platform at the southern end of Figure Eight Island decreased the width of the inlet by ~ 375 ft (from 1,215 to 840 ft) and its throat cross section by 40% (5,059 ft^2 to 3,057 ft^2). During the same time period the narrowing of the inlet and constriction of tidal flow was partially compensated by scour of the channel increasing maximum depths from ~10 to 18 ft (ATM, 2000). Continued degradation of the soundside channels between 1999 and 2001 resulted in shoaling of the ebb channel and partial infilling of the poorly defined marginal flood channel on the updrift Figure Eight shoulder (Fig. 15 A).

The reduction in size of Mason Inlet since the late-1970's was a product of the diminishing tidal prism that decreased from 67.1 x 10^6 ft^3 in 1995 (Cleary, 2002) to 24.7 x 10^6 ft^3 by 1999 (ATM, 2000). The declining tidal discharge at the inlet resulted from the interplay of the longshore sediment transport, high energy wave events and the landward movement of sand into the inlet by flood currents (Cleary and FitzGerald, 2003). These processes combined to produce long-term sand deposition inside the inlet that was evidenced by the shoaling of backbarrier channels.

From the late-1970's through the mid-1990's the tidal prism of Mason Inlet was significantly reduced due to sedimentation in the 3,950 ft-long Mason Creek, the acesss channel that connected the inlet channel to the AIWW. When this creek was devoid of intertidal shoals the inlet accessed a large portion of its tidal prism from the Intracoastal Waterway. During the late-1970's Mason Inlet was situated in front of the opening to Mason Creek. While in this position multiple lobes of sand formed and prograded landward into Mason Creek as well as into Banks Channel behind Figure Eight Island. As the inlet migrated southward large quantities of sand completely shoaled Mason Creek (Cleary and FitzGerald, 2003). This accumulation of sand effectively cut off the tidal exchange between the AIWW and Mason Inlet thereby vastly reducing the tidal prism (Fig. 15 A-B). As a consequence the migration rates were accelerated.

The only viable long-term management option for mitigating the increased erosion potential was the relocation of the inlet northward as much as possible (Figs. 15 B-D and Fig. 16). To that end, in early March 2002, a new inlet channel was excavated across the southern spit system of Figure Eight Island a site located approximately ~ 3, 020 ft northeast of the existing inlet. Several measures were undertaken to increase the tidal prism and lessen shoaling of the interior channels (Fig. 15 D). Most importantly Mason Creek was dredged along its length reestablishing the hydraulic connection between the inlet and the AIWW. A depositional basin was dredged inside the inlet to help prevent rapid shoaling that is normally a product of flood-tidal delta formation. The material from the inlet relocation dredging operations was used to close off the old inlet and nourish a segment of southern portion of Figure Eight Island (Fig.15 B-C).

Changes in post-relocation, inlet morphology have been considerable. The ebb channel has periodically shifted SW and NE since relocation as the system attempted to reach equilibrium. Erosion has been the dominant trend along the adjacent oceanfront shorelines as the planform of the shorelines adjusted to the new location of the inlet and the changing shape of the small ebb- tidal delta. Noticeable infilling of the interior feeder channels as well as the depositional basin has persisted since the ebb channel was relocated in March 2002 (Welsh and Cleary, 2007). The nearly clogged access channels are usually un-navigable unless they are dredged (Fig. 16). When maintenance dredging is required the beach quality material dredged from the throat, depositional basin and Mason Creek is placed along Figure Eight Island at the expense of the homeowners. The most recent maintenance operations occurred in January 2008. If dredging activities were to cease the inlet would likely close in a short period of time due to the reduced tidal flow and erosion of the oceanfront shorelines would temporarily increase as the barrier curvature is adjusted

Masonboro Island

Masonboro Island is an undeveloped barrier that extends along 8 miles of the coastline between Wrightsville Beach and Carolina Beach Extension (Figs. 14 and 17). Masonboro Inlet separates the island from Wrightsville Beach; Carolina Beach Inlet separates it from Carolina Beach to the south (Fig. 17 C). Masonboro Island was continuous with Carolina Beach until 1952 when Carolina Beach Inlet was artificially opened. Old Cabbage Inlet and other relict inlets (Fig. 17) are recognized by the geomorphic patterns found within the estuary (Cleary and Hosier, 1979). Most of the large dunes (12 ft elevation) are restricted to the northern portion of the island (4 mi) in the fillet of the Masonboro Inlet south jetty. The dunes along the remaining 60% of the barrier are very low and discontinuous (Cleary et al., 1999)

The sediment budget of Masonboro Island has been severely impacted by the artificially opening of Carolina Beach Inlet in 1952 and by the construction of the dual jetty system at Masonboro Inlet. Both modified inlets have impounded substantial volumes of material on an annual basis since modification occurred. The net reduction of sediment supply over the past 30-50 years that amounts to ~ 333,000 cy/r (Jarrett, personal communication, 1996) combined with the storm impacts have dramatically affected the manner and rapidity of the evolution of the barrier.

Most of the central (2.7 miles) and southern (2.7 miles) portions of the barrier were characterized by sparsely vegetated washover fans in the early 1990s. Many of these features extended well into the adjacent fringing marsh and into open water. The foredunes along much of the barrier were scarped or extremely low and in many places nonexistent. When Hurricane Fran made landfall in September 1996 the storm greatly exacerbated the generally poor conditions of the barrier. The Category 3 hurricane produced a storm surge (12.1 ft) that exceeded the 100-year flood level. The majority of the island with the exception of the extreme northern end was inundated and remained submerged for several hours (S. Rogers, personal communication, 1996). Post-storm aerial photography showed that the island was characterized by extensive washover-related features even within the fillet (Fig. 17 A). The storm eroded almost all of the foredunes and along the southern portion of the island dramatically reduced barrier profile (Doughty, 2006 and Doughty et al., 2006).

Between January 1993 and September 1996, the fillet shoreline prograded an average of 46 ft, despite the landfall of Hurricane Fran. This reach had historically prograded at an average rate of 16.4 ft/yr since 1980 when the south jetty was constructed (Cleary, et al., 1999). During this period the central segment of the island eroded an average of 56 ft while the southern segment eroded an average of 108 ft. Shoreline retreat in the vicinity of a small subaerial headland which separates the Carolina Beach Inlet-influenced segment from the inlet-fill segment (Cabbage Inlet) was limited to 39 ft; however, immediately adjacent areas experienced twice as much erosion as the headland-influenced reach. It appears that the small headland reach has acted as a hinge upon which the adjacent shoreline segments are translated at more rapid rates (Sault, et al., 1999).

Post-Hurricane Fran shoreline recovery (9/96 to 9/97) was restricted to the fillet where the shoreline prograded an average of 33 ft. In contrast, the central portion of the barrier retreated an additional 7 ft while the southern portion of the barrier eroded 13 ft. The combined effects of Hurricane Bonnie (8/98) and Hurricane Floyd (9/99), both Category 2 storms, rivaled the impact of Hurricane Fran (Fig. 17 B-C) Between September 1997 and September 1999 the shoreline within the northern reach of the fillet, previously characterized by significant progradation, was limited to less than 2 ft of accretion. The central section of the island was also significantly impacted by the hurricanes and retreated 52 ft. Shoreline recession steadily increased toward the Carolina Beach Inlet-influenced segment where 79 ft of oceanfront retreat occurred.

The net shoreline change between 1993 and 2002 varied substantially along the three major reaches of island. Shoreline progradation was limited to the extreme northern portion of the island within the fillet where the shoreline accreted an average of 26 ft. In contrast, the central and southern barrier segments retreated ~ 160 ft and 289 ft respectively. The island will continue to retreat along the southern portion and may depending upon the storm climate be detached during a major high energy event (Fig. 17 D).

Carolina Beach and Carolina Beach Extension

The barrier island chain of the Cape Lookout to Cape Fear section of the North Carolina Coast is interrupted at Carolina Beach (Figs. 1 and 18). Carolina Beach Extension represents the truncated barrier spit that existed before the opening of Carolina Beach in 1952. In essence it represents a portion of the former northward extending Masononboro Spit (Fig. 18 B and D). This section of the shoreline is sediment starved due to the impoundment of littoral material by Carolina Beach Inlet. As a result, a shoreline reentrant has formed south of the inlet (Fig. 17 B-D). This segment is a chronic washover zone due the general lack of dunes. Despite a severe shoaling problem, proposals to close Carolina Beach Inlet have not been favored because recreational and fishing boats anchored at Carolina Beach would be required to enter and exit the ocean at Masonboro Inlet, 8 miles distant from Carolina Beach Inlet.

The marsh-filled estuary found north, and again south, of Carolina Beach Extension does not exist behind the Carolina-Kure Beach mainland section (Figs. 1 and 19). This portion of the coast is characterized by a perched mainland beach. Elevations landward of the beach are 15 to 20 ft. Pleistocene-aged, erosion-resistant units underlie the mainland beach along the Carolina Beach shoreline segment. This shoreline has had a colorful history of shoreline stabilization attempts similar to those undertaken at Wrightsville Beach. Various generations of groins, berm construction and nourishment took place along this shoreline segment. The projects undertaken since development began (early 1900's) have proved to be short-term fixes; erosion of the mainland beach has persisted. Carolina Beach is one of the most frequently nourished beaches along the east coast. Historically the fill material for nourishment of Carolina Beach is derived from the maintenance dredging of Carolina Beach Inlet (Fig. 18 B). In addition to the aforementioned source of sand, an offshore borrow area was utilized in 1997 to nourish the oceanfront. It is likely that future projects will also rely on the inlet and the shoreface for sources of sand.

Kure Beach and Fort Fisher Beach

The shoreline segment from Kure Beach to Fort Fisher represents the continuation of the Carolina Beach shoreline segment (Fig. 19). The shoreline segment like Carolina Beach consists of a wave-cut platform incised into Pleistocene units of the headland with a thin perched beach (Moorefield, 1978; Meisburger, 1979; Cleary and Hoiser, 1979; Snyder et al., 1994, Riggs et al., 1995; Cleary et al., 1996 and Marcy and Cleary, 1997). All of the major hurricanes that have impacted this area, from Hurricane Hazel (10/54) to Hurricane Fran (9/96), stripped away the sand prism and exposed the underlying platform. In an effort to restore the beach in the aftermath of the 1996 hurricanes the USACE replenished an 18,000 ft long oceanfront segment of

Carolina/Kure Beach/ Fort Fisher reach (Figs. 19 and 20) with ~ 3.4 x10^6 cy of high quality beach fill (USACE, 1993a and 1993b). The borrow area was located in the hardbottom dominated shoreface off Carolina Beach. The site represented an anastomosed channel complex of the ancestral Cape Fear River that was incised into the Pliocene valley fill complex (Meisburger, 1979; Snyder et al., 1994; USACE, 1993b; Marcy and Cleary, 1997). The Pleistocene paleo- channels were estimated to contain in excess of 23 million cy of clean sand. This channel system as well as the other identified paleo-channels contains enough material to satisfy the local needs (Carolina and Kure Beaches) for at least 30 years.

Fort Fisher located adjacent to Kure Beach (Fig. 19 D) is characterized by erosion resistant, coquina Ls (calcarenite) that underlies the aforementioned humate sandstone and crops out along the intertidal beach (Figs. 20 A and 21). Friable, humate and iron-cemented Pleistocene sandstone prior to the construction of the seawall (Fig. 21) formed a 2.5 m high wave-cut scarp and terrace that backed the shoreline along headland and seaward of the Civil War Fort. South of Fort Fisher is the East Beach non-headland shoreline segment (Fig. 20 C) characterized by a barrier spit that overlies an inlet-fill sequence consisting of 35 ft of muddy estuarine sediments (Swain and Cleary, 1992). The shape and evolution of the coastal segments in vicinity of Fort Fisher is clearly related to the outcropping and underlying Pleistocene geologic units (Swain and Cleary, 1992; Riggs et al., 1995 and Cleary et al., 1996)

In the early part of 20th century, major sections of the coquina that crops out on the beach area were removed for road building and construction materials (Cleary and Hosier, 1977). Closure of an inlet south of Fort Fisher (subsequently discussed) and the removal of the coquina ultimately led to a shoreline recession exceeding 57 ft/yr between 1926 and 1931 (Beach Erosion Board, 1931). Following the hurricanes of 1954 and 1955, several small groins and rubble from storm related destruction were placed the embayment immediately south of the coquina exposures. In 1970 a rock revetment consisting of limestone from Castle Hayne was emplaced. Since the mid 1970’s until the late 1980s a variety of construction rubble was added to the site.

In order to mitigate the rapid erosion, a Beach Erosion Control Project was authorized in 1976 to protect the Civil War earthen-mound fortifications. The historic fort was reduced to approximately 50 % of its original extent at the time of the authorization. After obtaining a variance from the state, the project was initiated in 1995. Plans called for a 3,050 ft long rock revetment with crestal elevations of 10 - 16.5 ft, a base width of 70 ft, and an armored toe consisting of five ton interlocking STA-POD units (USACE, 1993 and Dennis, 1996). The project was completed in the spring of 1996 at a cost of ~ $ 4 million.

East Beach

The East Beach complex extends from Forth Fisher to and beyond the Brunswick County line to Smith Island (Cape Fear). The barrier extending from Fort Fisher is a 5.6 mile long complex spit which connects the Holocene sediments of the Cape Fear Foreland Fig. 22A) and the older Pleistocene headland section (Carolina-Kure-Fort Fisher). Migratory inlets have been a common feature along East Beach during the last 160 years. Extensive areas of marsh built upon flood tidal deltas fill the estuary behind East Beach (Zeke’s Island Estuary). Recently (mid 1999), New Inlet closed in a location where older inlets had closed after migrating 3.7 miles since 1949 (Swain and Cleary 1992 and Hasbrouck, 2007).

Historical records and charts show the original New Inlet opened in 1761 during a severe hurricane. The breach occurred in a low and narrow region known as the 'Haulover'. It is very likely that one or more pre-historic inlets preceded New Inlet. The inlet channel which formed in 1761 deepened and remained essentially stable until 1839 when it began to shoal and migrate in a southerly direction (Swain et al., 1991 and Swain, 1993). In 1854, attempts were made to close the breach which led to an accumulation of sediments in the Cape Fear River Channel to the west. In 1881, a dam ('The Rocks') was completed which effectively cut off tidal exchange between the Cape Fear River and the estuary riverward (landward) of East Beach. Between 1895 and 1960, a cycle of inlet opening, migration and closure was repeated three times along a 1.5 mile segment of the spit.

Construction of the dam not only produced a unique type of estuarine system, it also set the stage for subsequent erosion events along the updrift shoreline segment at Fort Fisher. Prior to inlet closure in 1881, a large asymmetric ebb shoal containing a minimum of 50 million cy of material fronted the Fort Fisher shoreline (Swain and Cleary, 1992). The highly skewed ebb delta acted as a natural breakwater and protected the updrift shoreline segment against direct wave attack. Closure of the inlet prompted the collapse of the ebb shoal as the tidal prism of the inlet was drastically reduced. The remobilized sediment infilled the former throat section and fed the newly developing spit (Swain and Cleary, 1992). Closure of New Inlet and the removal of the coquina were major anthropogenic events that have had a significant and long-lasting impact on this portion of the coast.

Bald Head Island

Bald Head Island is a residential barrier located at the mouth of the Cape Fear River Estuary (Figs. 22 A and 23). Bald Head Island, a 5.6 mile long barrier segment, represents the largest segment of the Cape Fear Foreland. Bald Head, and 3 smaller “islands” separated from it by tidal marsh, is part of once more extensive Holocene regressive sequence that has since been drowned by rising sea-level (Fig. 23). The origin of the Cape Fear Foreland as well as the other two Capes in North Carolina (Capes Hatteras and Lookout) is conjectural and have been related to a variety of mechanisms including ocean current eddies (Dolan and Ferm, 1968) and erosion of remnant Pleistocene river deltas (Hoyt and Henry, 1971). Data from the extensive shoals suggest the Capes may be relatively old and related to subtle structural features (Blackwelder, et al, 1982). Unpublished information supports the contention that the present Cape is one of a number of such features that have shifted southward since the mid Pleistocene.

Regardless of their antiquity or origin, the present day morphology of the three islands that form the foreland complex date from ~ 4.5 ka when sea-level rise is thought to have decelerated. The progradational phase during this period of sea level rise may have lasted 2,500 years or longer, the exact length is speculative for it is difficult to determine without detailed stratigraphic data and dates on the age of the stranded dune ridges. Since the last progradational episode, rising sea level has drowned the low swale areas between the ridges, all of which are now filled with tidal marsh and crossed by large tidal creeks (Fig. 23). The geometric arrangements of the historic multiple dune sets reflect the change in the pattern of the shoals immediately offshore both at the eastern and western end of the island. The eastern end is characterized by truncated forested beach ridges with sets of smaller multiple dunes oriented perpendicular to the ridge complex. During major storms the majority of the eastern shoreline (East Beach) is overtopped resulting in the formation of large overwash terraces which extend into the marsh.

The Cape Fear River Inlet is ~ 6,650 ft wide and is the largest inlet system in southeastern North Carolina (Figs. 1 and 22). The western segment of the estuary entrance shoals (ebb-tidal delta) contain as much as 85.0 million cy of material to water depths of 18 ft. Historically this large shoal segment has been a potential target area for nourishment operations in the area. The ebb channel (ship channel) serves as the entry to the Wilmington Harbor, North Carolina's primary commercial port, located ~19 mi upstream from the coast. Dredging of the Cape Fear River estuary and throat began in 1829. Additional major improvements of the ebb channel occurred in 1871 when the ebb channel dimensions were increased to ~ 12 x 100 ft. Between 1890 and 1985 the entrance channel was progressively widened and deepened to 40 x 400 ft (Cleary and Hosier, 1988 and Cleary, et al., 1989). In 2001 the ship channel was realigned (Fig. 28) to a south-southwest orientation, deepened an additional 4.0 ft and widened as such as 900 ft (USACE, 2008).

Since major modifications began in the late 1880's, ~ 70 million cy of material have been dredged from the entrance channel and its landward extension (USACE, 1989). The ship channel was deepened an additional 4.0 ft when it was realigned to a more southeasterly during 2001. Since major dredging operations began in the 1880's the cross-sectional area of the entrance channel has increased from 99,405 ft^2 to 120,825 ft^2 (USACE, 1989). Although data suggest the ebb-tdail delta volume should increase due to an increase in channel cross sectional area, and hence tidal prism, calculations show that the entire ebb-tidal delta (to – 18 f)t has lost ~17.8 million cy (Cleary, et al., 1989,).

Previous investigations (Cleary, et al., 1989 and USACE, 1989) of historic shoreline and shoal configurations changes indicated the reorientation and subsequent stabilization of the ship channel in the 1880's led to significant changes in the morphology and volume of the ebb-tidal delta (outer bar). Subsequent to the shore-normal realignment of the navigation channel in the

1880’s, large scale dredging led to segmentation of the ebb tidal delta and an eventual reorganization of the shoal complex into distinct east and west segments. Bathymetric data derived from historic charts indicate the larger, western Jay Bird shoal segment bordering the Oak Island shoulder (Fig. 24) has gained approximately 11.0 million cy, shoaled and extended seaward. By contrast, the eastern Bald Head Island shoal segment has lost 28.8 million cy of material, almost 45% of its 1857 volume (Cleary, et al., 1989). Concurrent with these massive losses, the shoreface off Bald Head Island deepened and steepened as the shape of the ebb-tidal delta was reconfigured.

Natural realignment of the ebb channel that occurred in the early 1880’s and the subsequent stabilization of the newly aligned channel prompted large-scale movement of sediment packages involving millions of cy. The large scale bar complexes migrated ashore and eventually attached along the western shoreline segment of South Beach during the late 1880’s until early 1920s (Cleary, et al., 1989). By 1923 the shoreline adjacent to the inlet along South Beach of Bald Head Island had prograded more than 2,625 ft. The eastern ebb-tidal delta segment fronting South Beach (Fig. 19 A-B), no longer being nourished by the eastward moving longshore current, continued to reconfigure as by-passing ceased. Since 1881 the eastern (Bald Head) lobe of the ebb-tidal delta which lost more than 28.8 million cy of material, has supplied ~13.1 - 19.6 million cy of material for the progradation of a portion of South Beach and West Beach.

Between 1888 and 1962 the majority of the oceanfront along the western portion of South Beach bordering the inlet throat was accreting (Cleary et al., 1989; USACE 1989). Net shoreline accretion ranged from 1,312 ft along the central portion of South Beach to 2,100 ft near the entrance to the estuary. The majority of the progradation of the West Beach spit occurred by 1900. Since ~ 1962, the western segment of the oceanfront along South Beach has been eroding (Figs. 25 and 26). Recession is due to a lack of sand by-passing and the continued reconfiguration of the often poorly-defined marginal flood channel juxtaposed along the southwestern portion of South Beach. Erosion has ranged from 210 ft along the central portion of South Beach to ~ 500 ft immediately east of entrance to the estuary. The emplacement of sandbag groins along much of the western segment of South Beach (Figs. 27 and 28) and the frequent nourishment efforts that have attempted to stave the erosion have met with marginal success.

Shoreline changes along West Beach are a function of the initial channel realignment, the eastern shoal segment's collapse, erosion of South Beach and the subsequent westward transport of materials into the flood channel and ultimately into the estuary (Figs. 25C, 26 and 28B). West Beach represents a large spit complex that has been nourished by the eastern segment of the ebb delta fronting South Beach. More than 1,475 ft of accretion occurred along the western margin of south Beach between 1857 and 1926 that resulted in the extension of the spit into the estuary and narrowing of the estuary entrance. Since 1926 the shoreline change trends have highly variable.

The realignment of the Ship Channel in 2001 was the subject of controversy. Opponents' concerns focused on the potential impact the newly aligned channel might have on the immediate shoreline due to the existing chronic erosion along both South and West Beaches. In February to July 2001 ~ 1.85 million cy of material derived from local dredging operations was placed along South Beach. Since 2001 an additional 1.62 million cy of have been placed on Bald Head Island as part of the USACE's Sand Management Plan. Since the ship channel was relocated ~ 4.05 million cy have been used to nourish the island (USCAE, 2008). The reader is referred to the various UASCE annual monitoring reports for more detailed information dealing with oceanfront and offshore changes.

Oak Island

Oak Island is located in Long Bay immediately west of the Cape Fear River and Bald Head Island (Fig. 29). The term Oak Island refers to a segment of the mainland isolated by the construction of the AIWW in 1930. With the exception of Yaupon Beach, a 1.6 mi long, subaerial headland segment, Oak Island consists of two transgressive barrier spits (Caswell and Long Beaches) comprised of a variably thick layer of sand that is perched on top of Holocene and Pleistocene units (Fig. 30). The headland dominated shoreline segment at Yaupon Beach (Fig. 30 A and C) is underlain by a Quaternary sequence consisting of a Pleistocene humate sandstone and Coquina limestone. This sequence extends beneath Oak Island, the nearby mainland and is identical to the sequence exposed along the Carolina Beach to Fort Fisher shoreline reach. Caswell Beach is a narrow 2.5 mile long spit that extends eastward from the headland toward the Cape Fear River estuary (Fig. 30 A and D). The remaining portion of Oak Island (Fig. 31) is composed of the “Long Beach” spit that extends 8.7 miles westward towards bordering Lockwood’s Folly Inlet. This morphologically complex spit fronts a narrow marsh filled lagoon.

Several shoreline reaches along the spit are characterized by low-relief parabolic dunes that likely represent small barrier island segments that were connected by an ancestral transgressive spit that extended westward from the headland. The relatively young peat units exposed along much of eastern portion of the spit indicate that recent inlet activity has been lacking along the area (Fig. 30 A-B). Radiocarbon dating indicated the peat units range in age from 1.0ka along Long Beach to ~ 1.8ka near the headland at Yaupon Beach. The stump forest along the headland segment that underlies the peat by contrast is several thousand years older and dates to 3.8ka (Griffin, et al., 1977).

The Oak Island inlet shoreline and oceanfront near Lockwood’s Folly Inlet have undergone significant periodic changes associated with the realignment of the ebb channel. From 1938 to the mid-1970s the channel orientation was favorable for accretion on the updrift Holden Beach shoulder while erosion along the downdrift Oak Island was the norm. During this period of time the western end eroded significantly. During the mid 1970’s until late 1984 the ebb channel deflected toward the updrift shoulder of Holden Beach reversing the erosion trend along Holden Beach (Cleary and Marden, 1999 and Cleary, et al., 2000). In the mid 1980s the ebb channel again deflected toward Oak Island renewing accretion along the western end of the spit. The ebb channel maintained a southeastern alignment until May 2001 when an ebb delta breaching event reoriented the ebb channel in a shore-normal fashion. Since 2002 the western Oak Island oceanfront immediately adjacent to the inlet has eroded and will continue to erode until the seaward portion of the outer bar channel deflects toward Oak Island (Fig. 31 B)

Many storms and hurricanes have impacted Oak Island during the past 150 years. Hurricane Hazel (10/54) was likely the worst storm to impact the area during the 20th century. In addition to the almost absolute destruction of the homes along the barrier, the hurricane's storm surge opened a wide breach east of Lockwood's Folly Inlet that remained open for several years. Farther eastward a number of small but temporary breaches were also formed. The elevated water level and lack of dunes led to the development of extensive washover fans and terraces that extended into the narrow remnants of the estuary near the headland.

With the exception of Hurricane Floyd, the hurricanes that impacted the area between July 1996 and October 1999 did minimal structural damage (Figs. 32 and 33). However, erosion of the narrow, artificially enhanced dune line and minor overwash occurred during all storms. Oak Island was spared the damage recorded along the New Hanover, Pender and Onslow Counties beaches after Hurricanes Bertha, Fran, and Bonnie due to its position in the lee of Cape Fear and the track and landfall location of the storms. Although Hurricane Floyd's storm surge only reached 7.9 ft m along Oak Island significant damage occurred (Figs. 32B and 33). Despite the fact that the oceanfront was in poor condition, only the oceanfront homes were seriously damaged. Where elevations were low washover fans extended across much of the coastal road. Damage would have been dramatically more severe had the storm surge reached its maximum potential.

The shoreface within this region is underlain by truncated Cretaceous to Eocene Age units that are mantled by a patchy mosaic of sediments of variable thickness, texture, and composition (Meisburger, 1977 and 1979; Cleary, 1999a and Cleary et al., 2000). The shoreface off Lockwoods Folly Inlet is dominated by low relief to moderate relief (1.0 - 5.0 ft) hardbottom areas. The units in the area offshore Lockwood's Folly Inlet are Cretaceous well-indurated limestone and silica-cemented sandstone. The majority of the eastern half of the shoreface is dominated by irregularly shaped, linear depressions that are floored by coarse muddy sand and muddy shell hash.

The complex surface sediment mosaic originates from the reworking of the underlying strata and sediments. Muddy sediment is also being added by the nearby Cape Fear River, particularly during flood stage conditions (Cleary, 1999). The veneer is easily reworked during storms, exposing rock units in areas where the sediment cover is thin. Vibracore data indicate that the shoreface consists of variably thick sequences of gravelly, muddy sands and muddy, sandy gravels intercalated with muds and muddy sands (Cleary, 1999a and Cleary et al., 2000) Thickness of the modern sediment package ranges from less than one inch in hardbottom areas to more than 11 ft in intervening regions. Seaward of the active beach (>30ft) thicker deposits appear to be confined to topographic lows that formed between the topographically higher portions of the more indurated units or within dissolution/collapse features.

Generally the sediment thickness increases in an easterly direction. With the exception of the areas marginal to the ebb-tidal delta the sediment sequence is usually thin landward of the 30 ft isobath. Ponding of sediments against some of the hardbottom scarps and in depressions between ridges may produce small localized areas of deposits that approach 10 ft in thickness. Granulometric analyses of cores indicated that the majority of the samples analyzed were muddy, sandy gravels and gravelly, muddy sands. The majority of sand units are generally muddy although some units are relatively clean.

Historically the USACE have been involved in the evaluation and implementation of a number of beach fill and storm damage reduction projects for Oak Island and nearby beaches during the past 50 years. The original 1966 authorized beachfill project for Oak Island consisted of a plan to nourish 9.0 miles of Yaupon Beach and Long Beach and involved the emplacement of 17.9 miilion cy of material. The original project designed for Oak Island (Long and Yaupon Beaches) was not implemented due to the failure of the Towns to provide their share of the costs (USACE, 1973). In the late 1980's the USACE reevaluated the inactive 1966 authorized project and concluded the original project was not justified. The Towns' share of the costs amounted to ~ $20 million, a prohibitive amount for small coastal communities.

In 1996 the Brunswick County Beaches Consortium was formed as an informal group of five beach communities that included: Holden Beach, former Long Beach, Yaupon Beach, Caswell Beach and Bald Head Island (Fig.1). The goals of the consortium were to develop a cost-effective, shoreline management plan and a funding program for shoreline management. Town officials of former Long Beach and Yaupon Beach formally requested the USACE to initiate a Reevaluation and Feasibility study of the Oak Island shoreline that began in January

1998. The study continues to date. Under separate legislation and authorization the USACE constructed the Sea Turtle Habitat Ecosystem Restoration project on former Long Beach (now Oak Island), an environmental restoration project authorized under authority of Section 1135 of the Water Resources Department Act of 1986 (Fig. 34). Construction of the 2.3 mi long project was completed in early 2001. The beach fill project involves the placement of 1.83 million cy of material along a portion of the eastern half of Oak Island. The eastern terminus of the project is located ~ 1.0 mi west of the Yaupon Beach Headland (Fig. 34). The borrow source for the ecosystem restoration project was locally termed the Yellow Banks Area, an existing upland dredge material disposal site (Fig. 31) located along the AIWW, ~ 1.0 - 2.2 mi to the northwest (USACE, 1999).

A second and more extensive project that provided storm protection for the reminder of Oak Island was a product of the Wilmington Harbor 96 Act authorized under the authority of Section 933 of the Water Resources Department Act in 1986. The beach fill material was a product of the aforementioned project that involved the deepening and realignment of a 5.8 mi section of the entrance channel to the Wilmington Harbor (USCAE, 2000 and 2008). Between July 2001 and April 2002 nourishment operations placed 1.18 million cy of material along a 3.6 mi segment of Caswell Beach and eastern Oak Island (east of the Environmental Restoration Project). An additional 1.27 million cy of beach fill was also placed along the western 3.6 mi of Oak Island west of the ERP (Fig. 35). It was estimated that as much as 1.0 million cy of material was needed on a three-year basis to satisfy the projected needs. The biennial maintenance of the various entrance channel segments is expected to involve the dredging and disposal of ~ 1.0 million cy of material. The results of the annual monitoring efforts will dictate the exact volume and placement of the fill. Oak Island is scheduled for renourishment operations in 2009 (USCAE, 2008).

One of the focal points of the requested USACE's General Reevaluation Report (GRR) for a separate storm reduction project along Oak Island was the availability of sufficient quantities of quality beach fill material for future re-nourishment cycles. Several studies had identified a variety of potential sources. One potential source included the western segment of the Cape Fear Estuary entrance shoals, locally known as Jay Bird Shoals (Meisburger, 1977 and 1979). This western segment of the ebb-tidal delta contains as much a 20 million cy of material. The USCAE vibracoring operations across the western entrance shoal recovered hundreds of cores that generally contained a mixture of clean sand interbedded with muddy sand and shell hash. On the basis of the core data the USACE concluded that while the shoals contained some compatible fill material the majority of the sediment sequences cored were muddy and therefore incompatible with the local beach material.

An additional potential borrow area for Oak Island that was re-evaluated was the shoreface off Oak Island (Cleary, 1999a and Cleary, et al., 2000). The new database provided a means of re-evaluating the information contained in the USACE 1973 General Design Memorandum for Oak Island and for planning future exploitation efforts. Interpretation of the data indicated that beach fill quality sand resources of significant volume (>1.9 million cy) were limited in the area. The broad belt of hardbottoms off the western portion of Oak Island precluded the utilization of this area of the shoreface as a potential source. Data complied from available cores indicated that sand units when present were thin and mud-rich. The muddy units were usually interbedded with thin units of cleaner sands and shell gravels. Paleo-channels that were identified on the limited seismic lines when cored proved to be filled with estuarine mud and muddy sand.

Some regions on the shoreface, however may contain beach fill quality sand but the volume and quality of material was difficult to determine due to the lack of detailed core and seismic data (Cleary, 1999). One marginally attractive target area is located off the western portion of Oak Island where the surface sediment is generally rippled fine quartz sand. The 0.78 mi^2 target area straddles the outer margin of the active beach at –30ft and extends to depths of –35ft. The site is located in a region of the shoreface between the mud-rich deposits of the upper shoreface and an area where the sediments are often thin and bordered by an area of limestone hardbottoms. Vibracores recovered from adjacent areas contain sequences of clean fine quartz sand with minor amounts of fine material. Thickness of the sand units ranged from ~ 5-7ft. These thicker deposits of sediment probably occupy a collapse feature or a topographic depression between limestone units that comprise the underlying framework of the shoreface. Whether or not this area is proven to contain compatible material it is highly unlikely that the shoreface will be a long-term borrow source.

Holden Beach

Holden Beach is a 8.1 mile long transgressive barrier bordered by Lockwood's Folly Inlet to the east and Shallotte Inlet to the west (Figs. 36 and 37). The island is comprised of several zones where large parabolic dunes are present that reach elevations of ~32 ft (Fig. 36). The intervening shoreline reaches connecting the topographically wider and higher segments are former inlet zones that are considered to be high hazard zones (Fig. 38). Although the two inlets that border the barrier have been reasonably stable during the past 70 years, significant changes have occurred along the Holden Beach oceanfront due to the changing position and alignment of the ebb channels of Lockwood's Folly Inlet (Cleary, 1999b) to the east and Shallotte Inlet to the west (Figs. 36, 39 and 40).

Inspection of historic maps and aerial photographs indicated that the barrier has undergone significant changes since the mid 19th century. During the 19th century Holden Beach was comprised of two narrow, islands separated by Bacon Inlet. Holden's Beach extended ~ 5.6 miles eastward to bordering Lockwood's Folly. Robinson's Beach located to the west of Bacon's Inlet was 2.5 miles long and bordered by Shallotte Inlet. Map information indicated the landward portions of both barriers were colonized by a forest consisting of oak, hickory maple species. Data derived from the plane table surveys suggest that the islands were stable and high enough for a forest to develop. On Robinson's Beach to the west, the forested area occupied the 1.3 mile long central segment of the island (Marden, 1999 and Marden and Cleary, 1999).

Significant inlet changes occurred in the area between 1858 and 1938 that impacted the barriers described above. Bacon Inlet maintained its stability while a new Inlet, Mary's Inlet, opened 1.7 miles east of Bacon Inlet. During this same period Lockwood's Folly Inlet migrated eastward ~2,300 ft while Shallotte Inlet migrated westward ~ 985 ft. By 1938, both Bacon and Mary's Inlets had closed resulting in an 8.1 mile long continuous barrier (Fig. 38). The most noteworthy morphologic change that occurred along the barrier between 1858 and 1938 was the development of large, parabolic dunes that comprised the eastern 2.8 miles of the island and a shorter 0.90 mile long segment east of Shallotte Inlet (Figs**.** 36 and 38)

Prior to the dredging of the AIWW (ca.1930), the Brunswick County barriers were accessible from the mainland by crossing the intervening marsh at low tide. Livestock were allowed access to the islands for grazing. In 1930, with the completion of the AIWW, livestock could no longer easily access the island. As grazing activities were curtailed, the stabilization of the parabolic dunes began (Marden and Cleary, 1999 and Marden, 1999). Similar changes also occurred along the other barriers in Brunswick County during this interval of time.

As mentioned the Brunswick County area has the highest storm surge potential along the North Carolina Coast. When Hurricane Hazel made landfall on October 15, 1954 at nearby Calabash, NC the 17 ft storm surge ultimately led to the massive destruction along the barriers and the formation of a number of breaches that dissected the island into numerous segments. These breaches ranged in width from ~2,300 ft immediately east of Shallotte Inlet to 5-10 ft elsewhere. An inlet ~985 ft wide opened at the former location of Mary's Inlet. This new inlet remained opened until the summer of 1955 when it was artificially closed. This scenario will likely be repeated along the low lying section of Holden Beach (Fig.38).

Information derived historic maps and coastal charts indicated that Lockwood's Folly Inlet existed as early as 1672. Seismic data from the shoreface suggests the inlet is a permanent feature related to the paleo-channel of the ancestral Lockwoods Folly River that extends across the shoreface (Cleary, 1996b). Prior to the Colonial Era, it is likely that the inlet migrated along a 1.5 miles long shoreline segment along the western portion of Long Beach (Oak Island). The presence of extensive peat outcrops and relict tree stumps along the Holden Beach shoulder (Fig. 36)indicate the inlet has not migrated to the west of the current location during the past several centuries.

The Holden Beach shoulder of Lockwood's Folly Inlet has been the site of chronic erosion during the past 70 years (Figs. 39 and 40). Erosion is a function of the alignment of the ebb channel that has been skewed toward Oak Island for much of the past 70 years. During the past 30 years erosion destroyed or led to the removal of the first row of homes along the Holden Beach oceanfront (Figs. 39 and 40). In an attempt to mitigate the erosion along the inlet margin fill material was placed along the oceanfront on a number of occasions without much success. One such attempt involved the construction of an artificial dune along the eastern 5 miles of the oceanfront between April 1997 and March 1998. The 202,150 cy of fill material was derived from the mainland and truck hauled to the site. Although nourishment records are incomplete the majority of efforts to mitigate the erosion have likely involved the placement of small volumes of material that were derived from the adjacent inlet. In late 2001 the USACE nourished the eastern portion of Holden Beach with ~ 0.50 million cy of material from the Wilmington Harbor Project. It is anticipated that the same reach will be renourished in 2009. The exact volume of material to be placed along the oceanfront is yet to be determined.

In 2001 an ebb delta breaching event led to the reorientation of the ebb channel at Lockwood’s Folly Inlet (Fig. 31 A insert) . The channel’s shore-normal alignment ultimately led to a reconfiguration of the ebb delta. The symmetric configuration of the outer bar has initiated a period of accretion along the inlet and oceanfront shorelines (Fig. X). Accretion along the inlet and oceanfront shorelines will continue as long as the ebb channel maintains an alignment that is nearly shore normal or deflects toward Holden Beach.

Shallotte Inlet that forms the western boundary of the barrier is morphologically similar to Lockwood’s Folly Inlet (Fig. 37). Historic maps and coastal charts indicate the inlet has existed for a minimum of 300 years. Evidence gleaned from an 1858 map suggested that an inlet, possibly Shallotte Inlet, was located 1.5 miles to the west of its current position during pre-Colonial days. The modern inlet has impacted the barrier in a manner similar to that of Lockwood’s Folly Inlet. When the ebb channel was skewed toward Holden Beach, the western shoulder on Ocean Isle was the site of erosion. Between 1962 and 2001 the ebb channel’s azimuth been averaged ~105° which has promoted significant progradation along Holden Beach Between 1970 and 2001 as much as 750 ft of progradation has occurred along the Holden Beach oceanfront (Fig. 37). The presence of the accrretionary wedge, characterized by vegetated parallel and recurved dune ridges, east of the inlet testifies to the important role the ebb channel alignment plays in oceanfront changes.

In early 2001 the USACE realigned the ebb channel in a shore-normal fashion (Fig. 37) and in the course of dredging operations excavated ~ 1.9 million cy of material that was placed along Ocean Isle. The realignment effort was expected to benefit both barriers that border the inlet. Since realignment the nature of inlet and adjacent oceanfront shorelines have changed.

The USACE are monitoring the changes on a periodic basis (USACE, 2002). It is likely that if the newly aligned channel maintains its original position oceanfront progradation will continue along the Ocean Isle margin while the former accretion zone will erode.

The shoreface off Holden Beach is similar in nature to the area offshore Oak Island. Much of the shoreface is underlain by Creaceous Age sandstones and sandy limestones. Many of the units are exposed forming extensive areas of harbottom (Marden, et al., 1999). Limited core date indicated that the sediment veneer is generally thin (<1.0 ft). More detailed geophysical and geological surveys are needed to fully evaluate the sand resource potential of the shoreface. It is likely that the potential will be low and if that proves to the case the only long-term large sand source for Holden Beach will be the Cape Fear Inlet interior channel segments and possibly Jay Bird Shoals.

Ocean Isle

Ocean Isle is a 5.4 mile long transgressive barrier situated between Holden Beach to the east and Sunset Beach to the west. Shallotte Inlet forms the eastern boundary while Tubbs Inlet forms the western boundary (Figs. 1, 40 and 41). The length of the barrier during historic times was determined by the position of unstable Tubbs Inlet that historically migrated in a westward direction. Tubbs Inlet and its predecessors have migrated along the barrier reach extending from immediately south of the bridge to western margin of the inlet a distance of ~ 2.75 miles. The island like the other barriers in Brunswick County is a composite feature with a 0.9 mile long and 1,000 ft wide barrier core composed of large parabolic dunes connected to the remainder of the remainder by low relief washover and breach prone barriers (Fig. 40).

Limited geological are available for Ocean Isle but it is highly likely that the evolution of this barrier is similar to that of nearby Holden Beach. All the islands in Brunswick County have one or two wide barrier core segments consisting of parabolic dunes. Historically the dune fields were mobile in the mid to late 19th and early 20th centuries. The available information suggests that prior to this period of time the sand comprising the parabolic dune segments was contained in prograded dune ridges.

Since the mid 19th century Shallotte Inlet has been a relatively stable inlet with respect to its location (Fig. 42). However in terms of a morphologic aspect, it has been highly unstable inlet which has led to significant changes along the Ocean Isle shoulder. These changes are directly related to the changing position and deflection/reorientation of the ebb channel, that facilitates changes in the symmetry of the ebb delta. Since the early 1970's a variety of erosion mitigation efforts have failed to stabilize the shoreline near the inlet (Fig. 43). When the ebb channel was skewed toward Holden Beach (SE alignment), the Ocean Isle margin eroded. This configuration existed from the mid 1960s until 2001 when the channel was relocated by the USACE. During the early 1960's when the channel alignment was ~ shore normal, accretion was common on both shoulders of the inlet. Deviation from this alignment promoted erosion on one or both shoulders as the ebb delta assumed an asymmetrical and altered its breakwater effect (Marden and Cleary, 1999 and Marden, 1999)

The Ocean Isle oceanfront and inlet shoreline have been the site of chronic erosion between 1974 and 2001. The truncations of the roads, the emplacement of a series of groins and the loss or removal of homes along this reach are testaments to this dramatic shoreline recession (Fig. 43). Since 1974 through 2004 the average erosion along the oceanfront immediately west of the inlet averaged ~375 ft and ranged from 320 to 425 ft. As mentioned above, the ebb channel was relocated in 2001 and aligned in a near shore-nomal orientation (Fig. 44). Since realignment the configuration of inlet throat, ebb delta and the Ocean Isle oceanfront and inlet shorelines have changed. The alignment has promoted gradual accretion along the Ocean Isle shoulder (Fig. x).

In May 2005 a small storm moved through the area and the associated elevated water level and increased wave activity eroded the oceanfront immediately adjacent to the inlet. In addition to the loss of the newly accreted material the storm destroyed several homes (Fig. 45) along this high hazard zone. Figure 47 depicts the condition of the oceanfront shoreline within this zone following Hurricane Ophelia that moved up the upcoast on September 20, 2005. The image clearly illustrates that this oceanfront segment will continue to erode during high energy events due the fact that its planform (curvature or protuberance) is avestige of a former accretionary period and shoreline armoring. The dashed yellow delineates the likely equilibrium shoreline in this area. The positive impacts of the relocation will continue along the inlet shorelines as long as the ebb channel continues to be aligned in a similar fashion that existed in 2001. However it remains to be seen if the any significant log-term buildup can occur along the armored oceanfront segment (Fig. 47). The USACE are monitoring the changes on annual basis and the reader is referred to these documents for additional information (USACE 2002).

During the USACE's relocation of the ebb channel a significant volume of material was excavated for the new ebb channel. Between March and May 2001 ~ 1.9 million cy of the material excavated from the ebb tidal delta was placed along the eastern 3.25 miles of Ocean Isle. Maintenance of Shallotte Inlet is expected to provide ~300,000 cy of material for renourishment that is scheduled on a three-year cycle. The majority of this material continues to remain in place as of August 2008.

The shoreface off Ocean Isle is similar in nature to the area offshore Holden Beach. The upper 1.0 – 3.0 ft of sediment cover consists of fine quartz sand with minor amounts of shell material and mud. The average thickness of the surface unit is ~ 2.5 ft and typically the upper sediment sequence grades downward into a muddy sand with minor amounts of shell material. This unit ranged in thickness between 0.5 -2.3 ft. The basal sediment unit is a gray mud to silt unit often containing pebble and cobble-sized lithoclasts (Sproat and Cleary, 1996). The sediment sequence is underlain by Cretaceous Age muddy sandstones and siltstones. Hardbottoms are not as frequent offshore Ocean Isle as they are farther eastward.

More detailed geophysical and geological surveys are needed to fully evaluate the sand resource potential of this segment of the Brunswick County shoreface. Isolated and irregular shaped target areas containing thin sequences of beach compatible material are likely present but only a very detailed exploratory effort is capable of mapping their extent and textural characteristics. If negative impacts result from the realigned ebb channel and the Holden Beach former accretion zone erodes to a critical point it is unlikely that Shallotte Inlet could continually be used as a major source of beach fill on a regular cycle. It is likely that if inlet dredging becomes a major erosion and regulatory concern the only long-term sand source for Ocean Isle will be the Cape Fear Inlet interior channel segments and possibly Jay Bird Shoals even though the source is some distance to the east.

In the short-term navigation improvement operations within Shallotte Inlet may provide small volumes of material for renourishment. One area yet unproven is located updrift of the eastern fillet of the Little River Jetties. This segment of the shoreface is certainly the most sand-rich area west of the entrance shoals of the Cape Fear Estuary. The prograded barriers in this area (Sunset Beach and Waites Island, SC) testify to the existence of a offshore sand source (buried channels or shoreface units).

Sunset Beach

Sunset Beach is located immediately east of Little River Inlet and the border of NC/SC. It is the westernmost developed barrier island in Long Bay (Figs. 1 and 29). Currently the island is 4.2 miles long and ~ 2,100 ft wide in the central portion near the pier (Fig 48 A). During the majority of the past three centuries it was comprised of a central core consisting of dune ridges and more recently large parabolic dunes and two flanking spits. The physiography of Sunset Beach (NC) reflects the more sand rich nature of the western portion of the shoreface. The 2,100 ft wide central portion of the island is characterized by a sequence of 10-14 ft high dune ridges that front an extensive field of vegetated, 16 to 30 ft high parabolic dunes. Historically the length of the spits that extended from the island's core varied depending upon the position of both Mad and Tubbs Inlets (Fig. 48). At present Sunset Beach is the only community in Brunswick County that has not requested federal assistance to stem land loss. In fact it is the only barrier in southeastern North Carolina that has prograded naturally during the past 50 years (Budde and Cleary, 2006).

Tubbs Inlet is small, relatively shallow unstable inlet that forms the eastern boundary of Sunset Beach and separates the island from adjacent Ocean Isle (Fig. 48 A). During the past century the inlet has migrated westward along a 1.25 mile wide pathway. Between 1856 and 1938 the average migration rate was ~ 66 ft/yr (Cleary and Marden, 1999). The rate of migration increased to an average of 131 ft/yr for the period between 1938 and 1970. In order to mitigate the rapid erosion of the eastern margin of Sunset Beach the inlet was relocated in December 1969 to a position 3,280 ft eastward that approximated the inlet's 1938 location (Masterson, et al., 1973). Subsequent to a period of adjustment to the new hydrodynamic conditions, Tubbs Inlet reversed its migration direction in the late 1970s and since then has been migrating eastward at variable rates (Marden and Cleary, 1999).

The current migration direction is opposite the direction of the net regional longshore transport and the inlet's historical migration direction (westward). The change is most likely due to alterations in the soundside channel dominance. Prior to relocation, Eastern Channel located behind Ocean Isle, was the major feeder channel (Fig. 48 A). The dredging of Jinks Creek, the western and historically minor feeder channel, during the relocation effort and subsequent maintenance cycles has allowed it to become the dominant channel, while Eastern Channel has shoaled considerably. The inlet's migration pattern since 1980 may also have been influenced by the construction of the dual jetties at Little River Inlet, which forms the western boundary of Bird Island, ~3.7 miles to the west (Fig. 48 B).

Mad Inlet, now closed, formed the western boundary of Sunset Beach and separated the barrier from undeveloped Bird Island, near the South Carolina border (Fig. 48 A-C). The very small, migrating inlet has been recognized on maps that date from the 18th century (Cleary and Marden, 1999). The inlet was highly unstable and ultimately closed in 1998, joining Sunset Beach to undeveloped Bird Island (Fig. 48 C). This scenario in the author's opinion represents the modern analogue of the evolution and development of the composite barriers in Brunswick County during the past 300 - 2,000 years.

Significant changes have occurred in the planform of the Sunset Beach barrier system, as well as the configuration of the inlet systems, since the late 1940s. During the period from 1949 to 1970, when the inlets converged and major storms impacted the area, the island's length decreased by ~5, 295 ft. During this interval of time, when the inlet systems toward each other, almost the entire oceanfront shoreline prograded an average of 196 ft and as much as 378 ft along the central portion of the barrier. During westward migration of Tubbs Inlet large swash bar complexes welded onto the Sunset Beach shoreline promoting buildup of the island's central portion. Additionally, periodic ebb delta breaching events also bypassed large bars that migrated onshore and attached to the oceanfront. Following the eastward relocation of Tubbs Inlet an additional 3,280ft length of shoreline was added to the eastern margin of the barrier. Subsequently the island entered into a period of relative stability from 1971 to 1979. During this interval, erosion rates as high as 10 ft/yr characterized the central portion of the oceanfront (Budde and Cleary, 2006).

From 1979 to 1989, the planform of the island was altered considerably as the barrier lengthened and subsequently eroded along the mid-barrier portion as the inlets continued to diverge. During this interval Tubbs Inlet began a more rapid eastward migration while Mad Inlet migrated westward, lengthening Sunset Beach by ~1,800 ft. Minor erosion continued along the island's center at a rate of ~8.5 ft/yr. The eastern portion of the spit was characterized by a slightly higher erosion rate (13 ft/yr), due to the fact that the reach no longer was nourished by Tubbs Inlet as it moved eastward (Budde and Cleary, 2006).

Between 1989 and 1998 the island prograded along its entirety. This island-wide trend was unique and dissimilar to the erosion trend normally associated with inlet divergence. The western end of Sunset Beach and the Bird Island segment also prograded as much as 650 ft during this period. The reach-wise accretion was due in part to the closure of Mad Inlet (1998) and the subsequent attachment of bars as the ebb tidal delta was reworked. By contrast the remainder of the island prograded only ~ 66 ft. As previously mentioned since 1998 following the closure of Mad Inlet Sunset Beach became contiguous with Bird Island (Fig. 48 A-C). This event effectively produced a composite barrier comprised of several spits and the core segments of Sunset Beach and Bird Island. The newly formed barrier measured ~ 3.7 miles in length. During this period the barrier eroded as the shoreline in the vicinity of Mad Inlet's closure zone was reconfigured and Tubbs Inlet continued to migrate in an easterly direction. The shoreline segment in the Mad Inlet closure zone eroded ~30 ft while the shoreline segment along the eastern end of Sunset Beach eroded an additional 62 ft (Budde and Cleary, 2006).

The combined influence of the spacing and migration habits of Mad and Tubbs Inlets has dictated the observed shoreline change patterns on Sunset Beach. Data clearly show that between 1949 and 2002 the mid-barrier portion exhibited a net progradation of as much as 395 ft, a trend unique to southeastern North Carolina barrier islands. Shoreline accretion increased toward the western portion of the barrier, east of the Mad Inlet closure zone, where as much as 426 ft of accretion occurred along the western spit extension of Sunset Beach. The shoreline change patterns west of the core of Sunset Beach may have been influenced by the dual jetty system at Little River Inlet ~2 km to the west. In contrast, along the Sunset Beach shoreline farther to the east (towards Tubbs Inlet), net accretion decreased dramatically due to the truncation of the oceanfront shoreline as the inlet-influenced erosion hot-spot shifted in an eastward direction. Net erosion has become the norm along the realigned shoreline of the elongating spit immediately west of Tubbs Inlet. Erosion along this shoreline reach is predicted to increase as the inlet continues to track in an easterly direction and the island lengthens. These results show that during periods of inlet convergence the island experienced net accretion, while showing net erosion during episodes of inlet divergence (Budde and Cleary, 2006).

The nature of the shoreface in this area is unknown. It is likely that a number of paleo-channels associated with the Little River drainage basin are incised into the underlying Cretaceous units. In the unlikely event that Sunset Beach needs to be nourished the offshore area warrants a detailed investigation.

FUTURE NOURISHMENT NEEDS AND OUTLOOK

Coastal communities in southeastern North Carolina are major tourist destinations and are prime examples of areas that have experienced rapid population growth and increased land values and revenues. The primary driving variable behind the rapid development was and continues to be the presence of a wide oceanfront beach. Therefore, management and preservation of this eroding feature is of utmost concern to homeowners, communities, and various government agencies alike.

Currently the State of NC has one of the most restrictive coastal development and shoreline stabilization policies in the United States. One of the more restrictive regulations, which went into effect in 1984, banned the construction of shoreline hardening structures. Other than the relocation of erosion-threatened homes, the only viable option available to homeowners and communities for erosion mitigation is beach nourishment. Much of the shoreline in southeastern North Carolina is situated within chronic erosion zones. Although the long-term average annual erosion rate for selected segments is only 2 ft/yr, some of these oceanfront segments are sites of massive nourishment projects, while others are desperate for assistance to stem the loss. Beach communities are under severe political and economic pressure to continue or initiate shoreline nourishment programs. As a consequence, all developed shorelines in southeastern North Carolina, except Sunset Beach, have a history of nourishment, have permits pending, or have requested assistance to stem the rapid land loss. The chronic long-term erosion, coupled with the effects of the frequent hurricanes and nor'easters that impact the region since, has prompted a regional inventory of the beaches and inlets in southeastern NC where the erosion history, storm impacts, nourishment needs, and availability of sand resources vary considerably (Fig.1). The end-product or ultimate derivative of the inventory is a coastwise beach and inlet management plan.

A primary, if not a major, focus of any beach and inlet management plan for any developed shoreline reach is the availability of sufficient sand resources to maintain the oceanfront beach for the foreseeable future. Predicting the availability of sand resources to satisfy the re-nourishment needs for the developed beach communities is extremely difficult at best. In this shelf sector with a limited sand supply an understanding of the role of the geologic framework is critical for formulating long-term management policies regarding coastal development and the availability and utilization of its sand resources. These data should be integrated with information pertaining to shoreline change patterns and inlet related sand resources available to mitigate shoreline recession. The potential environmental problems associated with inlet modification and the utilization of its resources should also be integrated into the assessment of the availability of sand for each specific site.

Figure 49 depicts the various shoreline segments that comprise the study area and the availability of sand resources for the next 50 years. The subjective rating is based upon the existing knowledge pertaining to the shoreface and inlet-related sand resources. There are a number of factors that will likely impact the outlook in the next several decades. The two most important variables are storms and economics. If the frequency of storms that impact southeastern NC increases during the next 30 years, then the nourishment potential will certainly decrease for

some of the communities situated in sand starved areas. A second uncertainty is the economic outlook. Given the fact that NC has not fared well of late from the viewpoint of federal funding for nourishment projects, it seems unplausible that it will change in the future. It is beyond the scope of this report to discuss all of the variables that influence the economics of future scenarios. Suffice to say that it will cost much more to place a cubic yard of sand on the oceanfront in the next several decades than it does at present. Local community, county and state government agencies alike will likely have a difficult time meeting their share of the costs. Consequently, the nourishment potential will vary both temporally and spatially along the coast. The long term availability will vary according to sand availability and compatibility, environmental restrictions storm climate and availability of funds.

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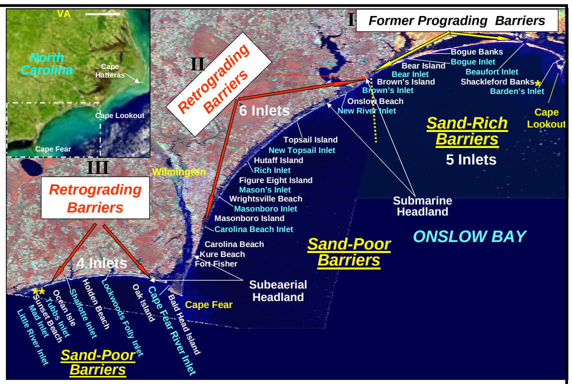


Figure 1. Photograph of Coastal North Carolina between Cape Lookout and Little River, SC (Bird Island) depicting locations of the barriers, mainland beaches, inlets and forelands. Three major oceanfront shoreline subdivisions were indentified base on the history of the Holocene history and the volume of sand comprising the barriers. Several additional subdivisions can be recognized on the basis of headland features.

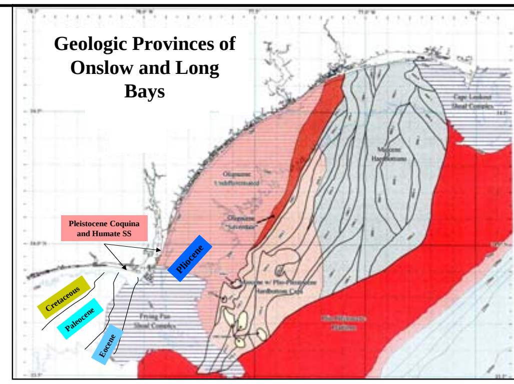


Figure 2. Geologic Provinces of Onslow and Long Bays, NC after Snyder, 1982, Riggs et al., 1985, Snyder et al., 1994 and Riggs and Cleary, 1998. Miocene units dominate the shoreface off Bogue Banks while Oligocene limestone and siltstone underlie the majority of the shoreface between Onslow Beach and Kure Beach. Pliocene limestone is exposed locally on the Fort Fisher - Kure Beach shoreface segment. Cretaceous, Paleocene and Eocene units underlie the Long Bay shoreface. Pleistocene units (coquina and partially lithified humate sandstones occur along the subaerial headlands at Fort Fisher-Kure Beach and Oak Island.

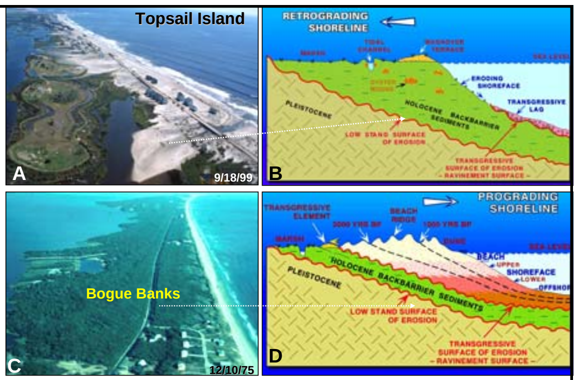


Figure 3. Photographs and cartoons depicting basic types of barrier islands in Onslow and Long Bays, NC. **A.** and **B.** depict sand poor barriers such as Topsail Beach (North Topsail Beach shown). **C.** and **D.** depict sand rich barriers such as the Bogue Banks – Browns Island shoreline segment .Cartoons (**B.** and **C.**) courtesy of Miles Hayes (RPI Columbia, SC). Most barriers in the study area have a history of retrogradation (transgressive features).

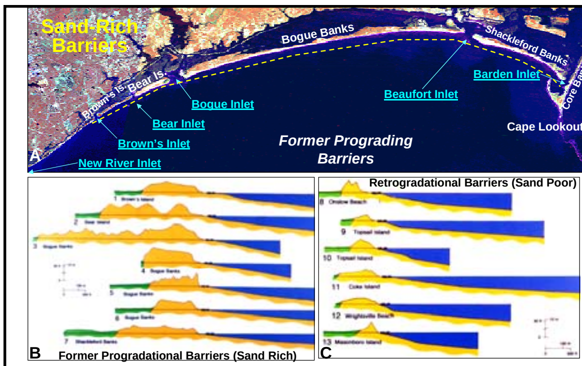


Figure 4. **A.** Image depicting location of sand-rich former prograding (regressive) barriers. Bogue Banks is a former prograding barrier (s) with a complex evolution. Shackleford Banks although wide and sand rich is not thought to be a former prograding barrier due to the thick, laterally continuous sequences of inlet fill that underlie the barrier. Brown's and Bear Islands characterized by large, high parabolic dunes. **B.** Cartoon depicting representative cross-sections of sand rich barriers that contain 15-25 times as much sand (volume)per mile of shoreline than do their transgressive counterparts. **C.** Cartoon depicting cross-sections of representative sand poor barriers in southeaster NC.

Figure 5. Photographs of the barriers in vicinity of the Cape Lookout foreland (CLF). A. Satellite image of the CLF. **B**. View (12/10/75) looking NE of dunes and forest on Shackleford Banks. **C.** West view (12/10/75) of Shackleford Banks and Barden Inlet. D. View (3/6/07) of Cape Point and associated shoals. Note large recurved spit developed in lee of coastal offset. Courtesy of Carteret Co. Shore Protection Office.

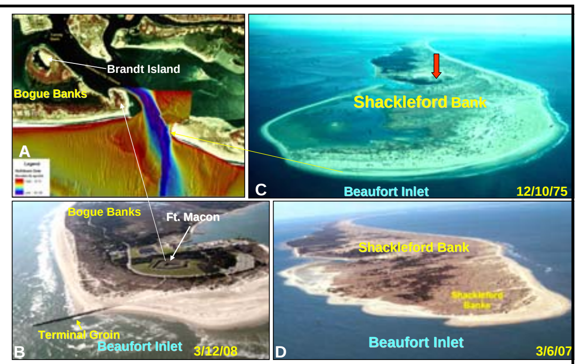


Figure 6. Views of Beaufort Inlet, eastern Bogue Banks and Shackleford Banks. **A.** Three-dimensional view of Beaufort Inlet and portion of ebb-tidal delta. Stabilized ship channel has bisected offshore shoal since the late 1930s leading to seaward growth of ebb platform and limited by-passing (courtesy of Chris Freeman –Geodynamics Inc.,). **B.** View (4/12/08) of Fort Macon terminal groin at eastern margin Bogue Banks. Note spit development within the inlet throat. **C.** East view (12/10/75) of Shackleford Banks depicting the low profile of the western segment of the barrier. Spit extending from forested area developed since the early 1950s as wide flood channel infilled. **D.** View (3/6/07) of the same area depicted in **"C".** Note changes in morphology and vegetation due to inifllling of swales and low areas in lee of recurved spit. Images used in **"B" and "D"** are courtesy of Carteret Count Shore Protection Office.

Figure 7. Photographs of Bogue Banks and Bogue Inlet. **A.** View (12/10/75) of western Bogue Banks depicting forested dune ridges and vegetated and unvegetated parabolic dunes on seaward side of old dune ridges. **B**. East view (12/10/75) of of eastern portion of Bogue Bank and forested high dune ridges and open water sound. Note lack of extensive development and vegetated parabolics. **C.** East view (12/10/75) of erosion along inlet margin and welding of swash bar along oceanfront adding to barrier progradation. **D**. East view (10/20/06) of Bogue Banks and eastern portion of Bogue Inlet. Note position of former and recently relocated ebb channel.

Figure 8. Aerial photographs of sand rich modified regressive barriers. **A.** North view (1985) of sand rich barriers. The northern portion of Onslow Beach, Brown's Island and Bear Island (Hammocks Beach State Park) represent regressive barriers that are now characterized by massive and often vegetated parabolic dunes that haves pilled over into the adjacent marsh. **B.** Bear Island (1985) along spit section of island. Note large migrating parabolic dunes. Bogue Banks is located at top of image. C. Brown's Island (12/10/75) central is flanked by younger spits note circular depressions (projectile craters). D. Onslow Beach (12/10/75) showing north end of system and

Figure 9. Aerial photographs depicting sand-poor retrogradational (transgressive) barriers along the New River Submarine Headland. **A.** Seaward view (12/10/75) of Onslow Beach (OB) the northernmost sand poor barrier in the study area. **B.** Southwest view (918/96) showing the washover fans and terraces formed by Hurricane Fran. Note the low and narrow profile of the barrier. Oligocene limestone is exposed at end of pier (blue arrow). **C.** Southerly view (8/26/98) of northeastern portion of Onslow Beach depicting erosion of fore-dune ridge by Hurricane Bonnie. Note lack of washover features along this transitional shoreline segment that is significantly more sand rich than the southern portion of OB. **D.** Northerly view (3/89) of the chronic inlet-related erosion along Onslow Beach. Note accretion on North Topsail Beach (bottom of image).

Figure 10. Image depicting Topsail Island and estuary. Inserts illustrate the shoreline conditions of the three barrier segments (Towns) that are located along the island. Note the general low and narrow profile of the majority of the barrier, particularly the northern portion. The shoreface is underlain by Oligocene limestones and calcareous siltstones. Thick sediment sequences are localized along the hardbottom dominated shoreface and most potential borrow areas for beach fill are yet unproven in terms of compatibility with the native beach material.

Figure 11. Aerial photographs of Hutaff Island and closure zone of Old Topsail Inlet (8/98). **A.** North view (12/10/75) of Lea, Old Topsail Inlet and Hutaff Island . Note presence of dune field and lack of washover features. **B.** South View (8/13/00) closure zone (6/98) washover fans and Rich Inlet. **C.** North view (8/13/00) of former inlet area and washover terrace and New Topsail Inlet **D.** South view (1/20/08) of the evegetation of the extensive washover terrace and erosion of inlet margin.

Figure 12. Aerial photographs depicting the morphology and shoreline of Figure Eight Island and the bordering inlets. **A.** Image (3/04)showing the relatively narrow and topographically low-nature of the sand-poor barrier. Rich's Inlet is a relatively stable inlet although there has been slight shifts in the ebb channel's position nthat has led to erosion along the northern end of the island. Courtesy of the New Hanover Co. Engineering Dept. **B.** Northward view (4/14/03) of the island. Mason Inlet a migrating system was relocated in March 2002. Maintenance dredging of the access channel and sound area provides material for periodic nourishment of the barrier. The insert depicts the historic accretion zone downdrift of Rich Inlet. This area is now eroding due a slight NE shift of the ebb channel.

Figure 13. Aerial photographs of Wrightsville Beach and Masonboro Inlet Jetties. **A.** Southward view (1994) of barrier and nourishment. Maintenance dredging of interior channels provides fill. **B.** Northward view (10/12/96) of the oceanfront after Hurricane Fran. Note lack of substantial washovers along barrier except near "bump" in the shoreline**. C.** Southward view (8/28/98) of Mason Inlet and northern portion of Shell Island (Wr Bch) after Hurricane Bonnie. Note erosion of dune field and washover along "bump" segment. Also note the inlet shoreline is armored with sand bags (SB). **D.** Southward view (5/26/02) of recently renourished oceanfront. Note fillet development on Masonboro Is.

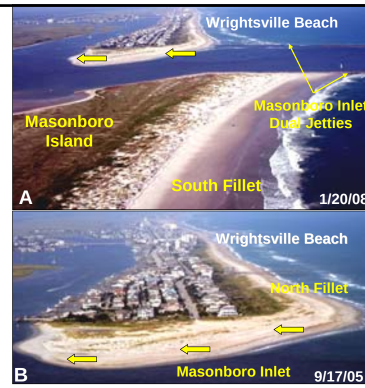


Figure 14. Photographs of Wrightsville Beach, Masonboro Inlet and Masonboro Island. **A.** Northward view (1/20/08) across inlet and fillet. Shoreline in the mid 1960s was approximately just seaward of building line. Note shoreline protuberance along upper part of image. This position marks the location of Moore's Inlet which was artificially closed in 1965. **B.** Northward view of wide dune field and spit extended into inlet. Sediment is derived from overtopping the weir during high tide conditions and then subsequently is transported by flood currents into the throat and estuary.

Figure 15. Aerial photographs of Mason Inlet and adjacent Figure Eight Island and Shell Island (Wrightsville Beach). **A.** Northward view (12/23/00) of inlet showing clogged throat and deterioration of sound-side channels. **B.** Northward view (1/30/02) showing inlet relocation efforts. Note placement of fill on Figure Eight Island. **C.** North view (3/7/02) depicting official opening of relocated inlet. Note scale of nourishment (> 0.5 Million cy) on Figure Eight Island. **D.** Landward view (5/26/02) of inlet, depositional basin and shoal-free access channel. Note growth of ebb tidal delta and bar migration into inlet throat.

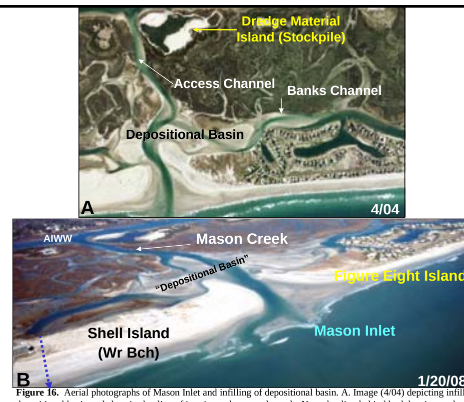


Figure 16. Aerial photographs of Mason Inlet and infilling of depositional basin. A. Image (4/04) depicting infilled depositional basin and chronic shoaling of interior and access channels. Note shoaling behind both barriers and development of tidal marsh on emerged shoals. Note condition of confluence of AIWW and access channel. Courtesy of New Hanover Co. Engineering Dept. B. View (1/20/08) of recently dredged interior channels and placement of fill material on Figure Eight Island. Note ebb delta size and former location of inlet (blue arrow).

Figure 17. Photographs of Masonboro Island. **A.** North view of Hurricane Fran's impact. **B**. North view of Hurricane Bonnie's Impact. **C.** South view of washover terraces and small headland. **D.** North view of headland, washovers and lack of dunes.

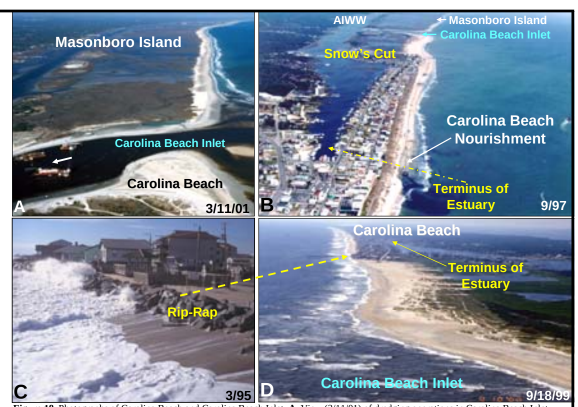


Figure 18. Photographs of Carolina Beach and Carolina Beach Inlet. **A.** View (3/11/01) of dredging operations in Carolina Beach Inlet. Masonboro Island is deprived of sand due to adjacent modified inlets. **B.** View (9/97) of disposal of fill material along oceanfront. Carolina Beach is comprised of a mainland and barrier portion. Note recession of shoreline north of pier that is related to the inlet. **C**. View (3/05) of rip-rap along oceanfront. **D**. South view (9/18/99) of eroding washover-prone segment and oceanfront reach where rip-rap occurs.

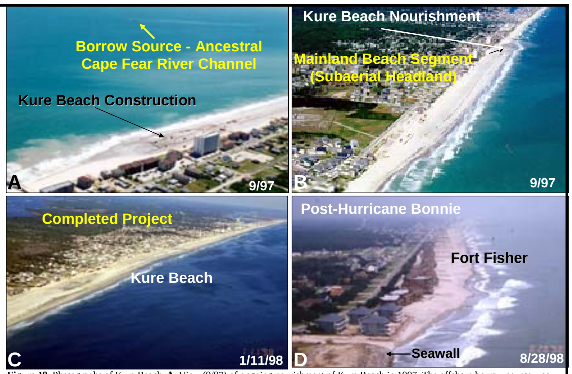


Figure 19. Photographs of Kure Beach. **A.** View (9/97) of ongoing nourishment of Kure Beach in 1997. The offshore borrow source was a segment of the Pleistocene channel complex of the "Cape Fear River". **B.** View of disposal of the high quality beach fill along Kure Beach. Note widths of constructed beach and adjacent unnourished segment. **C.** View of completed project (1/11/98). **D**. Northward view of the Forth Fisher and Kure Beach oceanfront after Hurricane Bonnie. The Forth Fisher Seawall is located immediately downdrift of the terminus of the beach fill.

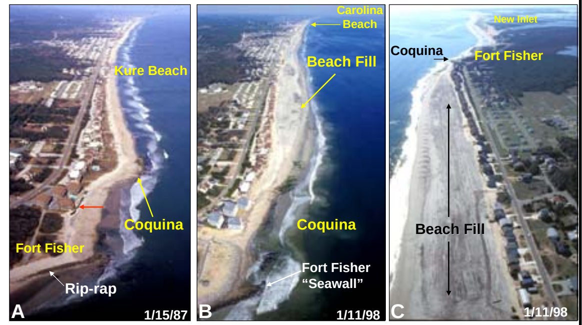


Figure 20. Aerial photographs of the Fort Fisher/Kure Beach oceanfront. **A.** Northward view (1/15/87) showing the influence of the coquina exposure. Notice the position of the HWL and the armored shoreline (red arrow). Hurricane Fran (9/96) eroded all of the dunes along this region. **B.** Northward view (1/11/98) of oceanfront after completion of 1997 nourishment project. Note lack of dunes – compare to "**A**". **C**. Southward view (1/11/98) of the nourished oceanfront and the terminus of the project. Note the shoreline offset south of Fort Fisher and the seawall. The nature of the underlying geology and paleo-topography (unconsolidated inlet and valley fill) has led to more rapid erosion.

Figure 21. Aerial photographs of the Fort Fisher Kure Beach Headland area. The humate ss. and coquina ls. imaged in the inserts underlie much of this region and portions of the inner shoreface where the more erosion resistant coquina forms relatively high relief hardbottoms such as Sheephead Rock. These units are also exposed on Oak Island headland segment. Note the influence of the coquina oceanfront shoreline. The more erodible humate ss. was exposed along significant stretches of the Kure Beach oceanfront after Hurricane Fran. This marker horizon can be traced southward for several miles toward Cape Fear.

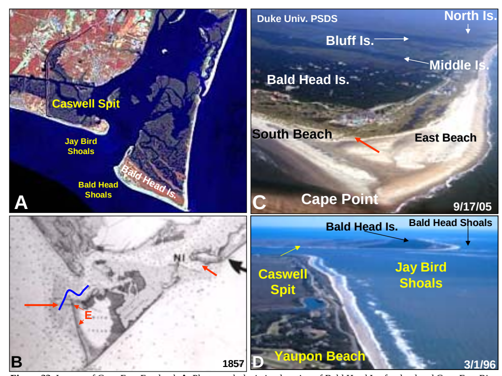


Figure 22. Images of Cape Fear Foreland**. A.** Photograph depicting location of Bald Head Is., foreland and Cape Fear River Inlet. **B.** Map (1857) depicting the shape of Bald Head Is. and the presence of New Inlet along East Bch. Note the alignment of the ebb channel along Smith Is. and the erosion (E) along the barrier. C. View (9/17/05)of Cape Point and East and South Beaches. Minor flooding and dune scarping occurred along East Beach. Note truncated dune ridges and swales between the active beach and the vegetated area in vicinity of the Shoals Club. **D.** View of West Beach and Cape Fear River Inlet.

Figure 23. Aerial photographs of Bald Head Island. **A.** Seaward view (3/3/96) along South Beach depicting a lack of a fore dunes and minor washover features. Note position of HWL. **B.** Westerly view (3/3/96) of erosion hot-spot along South Beach and unprotected structures on the oceanfront beach. Insert provides extended view of the foreland and the spatial relationship of the beaches.

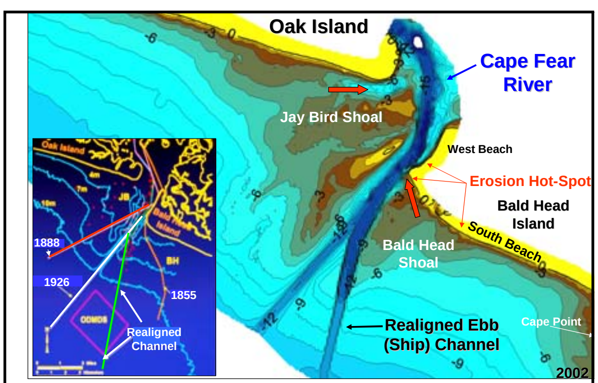


Figure 24. Map depicting realignment (2001-02) of the ebb channel (ship channel) across the ebb tidal delta. Relocation of the ebb channel has further reduced the size of the segment (Bald Head Shoal) of the ebb delta fronting Bald head Island. Reconfiguration of the BHS may promote the erosion (by flood currents) along the point where the linear bar is attached to the island (BHI red arrow). Insert depicts the various channel positions since 1855 . Since 1926 the channel has been stabilized and no wet to east by-passing has occurred (Cleary and Hosier, 1987). Image courtesy of Chris Freeman Geodynamics.

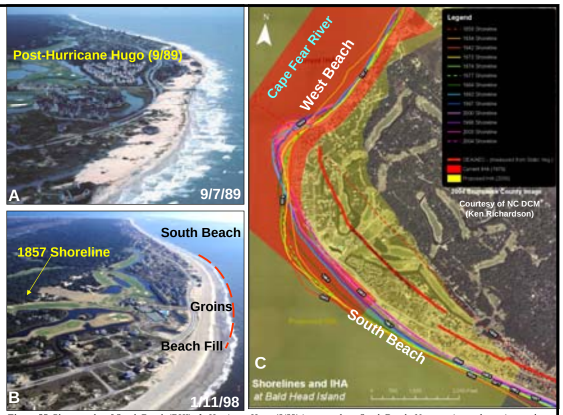


Figure 25. Photographs of South Beach (BHI). **A.** Hurricane Hugo (9/89) impacts along South Beach. Note erosion and massive washover terrace. **B**. Nourished oceanfront and groins. Compare **A.** and **B. C.** Map depicting shoreline positions within IHA since 1934. Bald Head Island has not been nourished by natural by-passing for scores of years due to the depth of ship channel and ebb shoal segmentation.

Figure 26. Photographs of South and West Beaches (BHI). **A.** View (3/01) of nourishment along South Beach. Note erosion hot-spot. **B**. Westward view (3/11/01) of point of slurry discharge along erosion hot-spot. The marginal flood channel impinges upon the oceanfront and inlet margin resulting in truncation. Note position of road and previous position of HWL. **C.** Map depicting erosion rates within IHA. Erosion rates represent long-term averages and do not depict the period changes related to shoal reconfiguration .

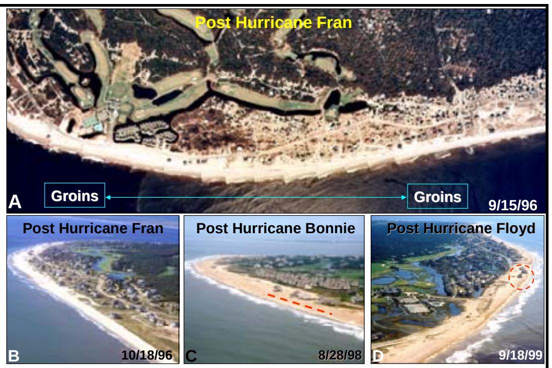


Figure 27. Aerial photographs of recent hurricane impacts along South Beach (BHI). **A.** View of washover topgrapghy formed by Hurricane Fran (9/96). Note extensive groin field. **B.** Westward view (10 18/96) of South Beach one month after Hurricane Fran. **C.** View of erosion and extensive washover terrace formed by elevated water level associated with Hurricane Bonnie (8/98). **D.** Eastward view (9/18/99) of South Beach in aftermath of Hurricane Floyd. Note width of beach near homes (circled dashed line) – compare to beach width in "**C**" (red colored dashed line).

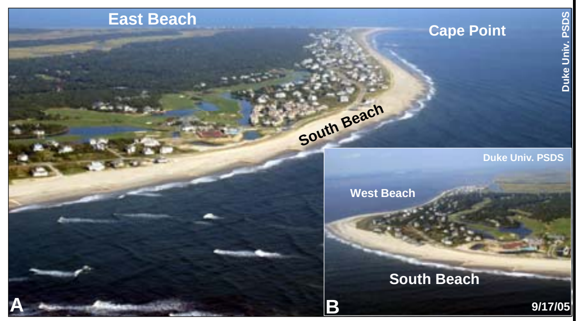


Figure 28. Aerial photographs of East and South Beaches following the passage of Hurricane Ophelia (9/17/05). **A.** eastward view of South Beach on Bald Head Island depicting minor erosion of dune line. The hurricane remained offshore and tracked upcoast. **B**. View of the Point area and the erosion hot-spot were only minor scarping occurred.

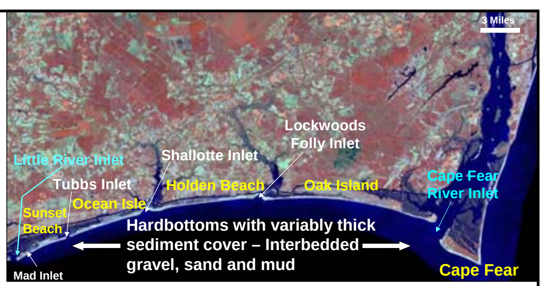


Figure 29. Image depicting the general nature of the Brunswick County shoreline that includes three barrier islands Holden Beach, Ocean Isle and Sunset Beach, two spits (Caswell and Long Beach) attached to the Yaupon Beach Headland and the Cape Fear Foreland. Tubbs Inlet is an eastward migrating inlet. Mad Inlet (closed since '98) was also a migrating inlet. Lockwood's Folly and Shallotte Inlets are morphologically similar and are relatively stable although the orientation of the ebb channels historically have changed through time leading to oceanfront changes. The Cape Fear River Inlet (estuary) is the largest system in SE NC and has been stabilized by large- scale dredging since the late 19th century. The shoreface is underlain by Cretaceous and early Tertiary units that are capped by a variably thick sequence of gravel, sand and mud. The majority of the gravels are lithoclasts derived from the hardbottoms while the mud is derived from the CFR westward extending plume. The region off Sunset Beach/Little River/Waites Island, SC appears to be sand rich in comparison to the barriers to the east. Most of the shoreface has little potential for beach fill quality sand. The maintenance dredging of Shallotte and possibly Lockwoods Folly Inlets and their AIWW confluences may provide small volumes of material. Consequently the Cape Fear River Inlet ebb-tidal delta and the lower tangents of the ship channel will likely the source areas for large scale nourishment projects.

Figure 30. Photographs of Oak Island features. **A**. Location image. **B.** East view (3/28/94) of western spit attached to headland and infilled "lagoon". Barrier consists of a thin low strip of sand. **C.** West view of headland and western spit (former Long Beach) **D.** View (3/1/96) of Eastern spit (Caswell Beach) attached at headland extending into Cape Fear River Inlet (estuary).

Figure 31. Photographs of Oak Island features. Oak Island is actually composed of a headland segment, separated from the mainland by the AIWW, and two spits extending east and west from the headland **A**. Location image depicting relationship of major morphologic features. **B.** East view (1/20/08) of western spit attached to headland at Yaupon Beach. Barrier widens in a westward direction toward Lockwood's Folly Inlet of a thin low strip of sand. **C.** West view of headland and western spit (former Long Beach) **D.** View (3/1/96) of Eastern spit (Caswell Beach) attached at headland extending into Cape Fear River Inlet (estuary).

Figure 32. West views of Oak Island. **A**. West view (3/96) of the western spit. Note position of homes with respect to the HWL and the general lack of fore-dunes. **B.** View (9/17/99) of same general area in **"A"** in the aftermath of Hurricane Floyd. Note the note the lowered profile and extensive washover features. Hurricanes Fran (9/96) and Bonnie (8/98) also caused erosion and structural damage.

Figure 33. Photographs of damages associated with Hurricane Floyd (9/19/99). **A.** View of oceanfront homes, washover features and debris from understory areas. **B.** East view showing eroded dune area washover fan undermining of road bed. **C.** View of damaged homes, exposed septic tank, eroded road and concrete footpad. Note extremely flat profile. **D**. View of several homes along the oceanfront. Note the lack of dunes in the field of view. House with red siding is referenced (red ellipse) for comparison purposes with subsequent images.

Figure 34. Photographs of the Oak Island 2001 ERP nourishment operations. **A.** East view (3/8/01) of the condition of the shoreline before nourishment. Note red sided home and lack of dunes. **B**. View (3/8/01) of slurry discharge zone. Note condition of oceanfront shoreline position of recent HWL. **C.** Aerial view (3/11/01) showing the construction of a portion of the ERP. Note width of restored beach. **D.** Eastward view of ERP and the pipeline from Yellow Banks, the borrow area for the beach fill material

Figure 35. Aerial photographs (10/16/01)of the Section 933 Nourishment Project along Oak Island and Caswell Beach. **A.** East view of the 933 project along Caswell Beach. **B.** Landward view of nourished oceanfront along shoreline segment of infilled "lagoon". **C.** View toward Caswell Beach and nourished shoreline. **D.** Westward view from headland of nourished oceanfront. Nourishment segments associated with the 933 project occur to the east and west of the ERP segment.

Figure 36. Aerial photographs of Lockwood's Folly Inlet, Holden Beach and Oak Island. **A.** Westward view (3/81) of Holden Beach and the parabolic dune field. The dark green represents shrubs that have colonized the swales and flanks of the dunes. The topographically higher areas are located along this portion of the barrier. **B.** East view (11/98) of erosion zone along inlet ad oceanfront. Channel alignment controls erosion trend. **C.** East view (10/01) depicting continued erosion of the oceanfront and development within the parabolic dunes. **D**. West view (1/20/08) Depicting realigned ebb channel (natural) and erosion of Oak Island oceanfront and initial buildup of Holden Beach.

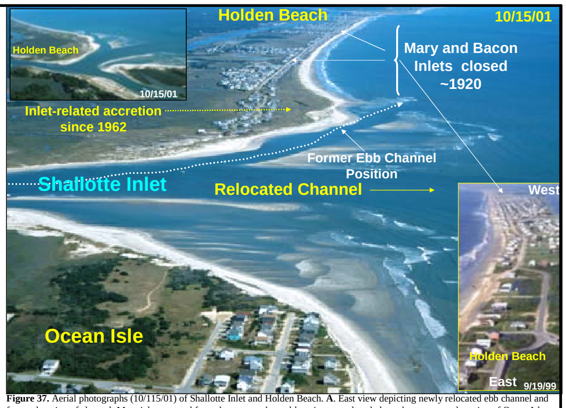


Figure 37. Aerial photographs (10/115/01) of Shallotte Inlet and Holden Beach. **A**. East view depicting newly relocated ebb channel and former location of channel. Material excavated from throat new channel location was placed along the east central portion of Ocean Isle. Note recent accretion along inlet margins and along the OI oceanfront. The low portions of the Holden Beach barrier are former inlet zones. Insert depicts location of closure zones and depicts the difference in the eastern and western portions of the barrier.

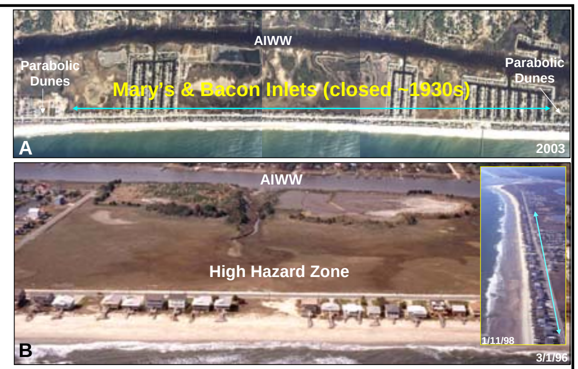


Figure 38. Aerial photographs of Holden Beach and inlet closure zones. **A.** View (2003) of low, narrow island segment connecting barrier segments comprised of parabolic dunes. Mary's and Bacons Inlets closed in the 1930s leading to the lengthening of oceanfront shoreline. **B.** View (3/1/96) of high hazard zone. Note the width of the barrier and the position of the HWL. The fact that the greatest storm surge potential occurs along this section of North Carolina's Coast makes this shoreline segment and others like it highly vulnerable to storm impacts. Insert depicts the location of the closure zone.

Figure 39. Photographs of the eastern portion of Holden Beach. **A**. West view (3/86) of eroding shoreline and houses stranded on recreational beach. Note bulkheads, timber groins and vestiges of seawalls that litter the beach. The eastern portion of Holden Beach shoreline near the inlet has been a chronic erosion zone since the late 1970s. **B**. West view (11/7/97) of same area in "**A**" retreat of the shoreline, removal of all but one home and a refurbished dune/dike composed of truck hauled sand. **C**. Aerial photograph of house on beach and peat exposure. Insert depict dike along road. **D.** Aerial photograph depicting shoreline and chronic erosion zone. Note the homes fronted by bulkheads and remnants of those destroyed.

Figure 40. Aerial photographs (3/10/03) of Ocean Isle. **A.** Photograph depicting the western portion of the barrier from Tubbs Inlet to the bridge. Note ebb channel of Tubbs Inlet is positioned along margin of Ocean Isle. Tubbs Inlet is migrating eastward opposite its historic migration direction. Also note that East Channel is clogged and hence with no appreciable tidal flow. Insert photo depicts the 1949 condition of area. With exception of parabolic dune segment the barrier is generally low and vulnerable to damage associated with storm surge. **B.** Photograph of the eastern portion of Ocean Isle depicting numerous finger canals and erosion hot-spot along margin of Shallotte Inlet. Note recent accretion along inlet shoreline and wide nourished beach. Beach fill was derived from the relocation of the ebb channel in 2001. (Photographs courtesy of USCE Wilmington District Office)

Figure 41. Oblique aerial photographs of Ocean Isle. **A.** West view (3/11/95) of southern portion of Ocean Isle showing clooged East Channel and accretion along inlet margin. **B.** East view (3/3/96) of barrier and curvature of oceanfront. Note large welding swash bar.

Figure 42. Aerial photographs (March 1996) of Shallotte Inlet and adjacent Holden Beach and Ocean Isle. Eastward view in background depicts the chronic erosion zone along the Ocean Isle oceanfront and the accretion zone along Holden Beach. The ebb channel is skewed toward Holden Beach, a configuration that favored erosion of the OI shoreline by flood and wave induced currents. Insert depicts a westerly view of the inlet and the erosion along Ocean Isle. Note truncation of the roads and the lack of protection afforded by the breakwater effect of the ebb-tidal delta. The buildup of the HB shoreline stemmed from the attachment of swash bars and the indirect influence of their attachment on updrift shoreline accretion. Note geometry of accretion wedge (dune ridge sets)

Figure 43. Photographs of the Ocean Isle inlet-related chronic erosion zone near Shallotte Inlet. **A.** View (9/84) of groins and rip-rap along oceanfront. The groins were emplaced due to the deflection of the ebb channel toward Holden Beach. Note the location of homes with respect road intersections for comparison purposes with subsequent images. **B.** Landward view (9/84) depicting the timber groins and position of the HWL with respect to the structures. **C.** View (3/28/94) of same general area depicted in **"B"** note the removal of a number of homes, the position of the groin field and the amount of erosion that occurred during the previous 10 years.

Figure 44. Aerial photographs of Shallotte Inlet. **A.** View (2/01) of skewed ebb channel, erosion along Ocean Isle and accretion on Holden Beach. **B.** View (5/02) of realigned channel. **C.** View (3/03) of accretion along OI margin of inlet. **D.** View (9/03) continued accretion along inlet margins. Compare nature of inlet margin and oceanfront changes (10/01 – 1/08) due to realignment in **E. F.** and **G.**

Figure 45. Eastward view of the Ocean Isle oceanfront and the nourished segment of the beach. The fill was derived from the realignment of Shallotte Inlet's ebb channel in late 2001.

Figure 46. Photographs (5/17/05) depicting and damage to homes in vicinity of Shallotte Inlet in May 2005. Location of images in **B-D** are referenced on the aerial photograph (**A**) dating from September 2003. Despite minor buildup of the oceanfront since inlet relocation the elevated water levels and wave activity related to a small storm caused destruction of several homes. Compare the location referenced on the image above **"A"** with Fig. 44.

Figure 47. View (9/20/05) of Ocean Isle west of Shallotte Inlet. The chronic erosion zone is related to the deflection of Shallotte Inlet's ebb channel toward Holden Beach. Note the nature of the building lines and the truncation of the roads. The little damage caused by Hurricane Ophelia only exacerbated the inlet-induced erosion. If the ebb channel is aligned in a shore-normal fashion or skewed toward Ocean Isle the oceanfront will prograde. The insert depicts the conditions of the same area in 1984. Note position of homes and groins. Background image courtesy of Duke University's PSDS.

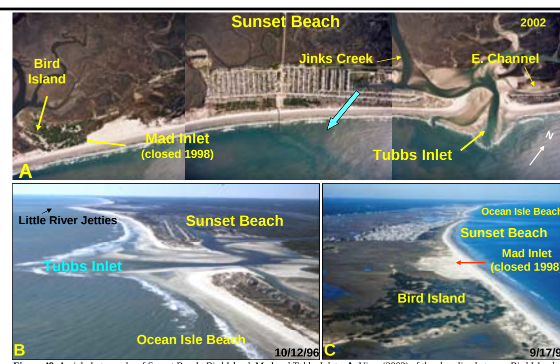
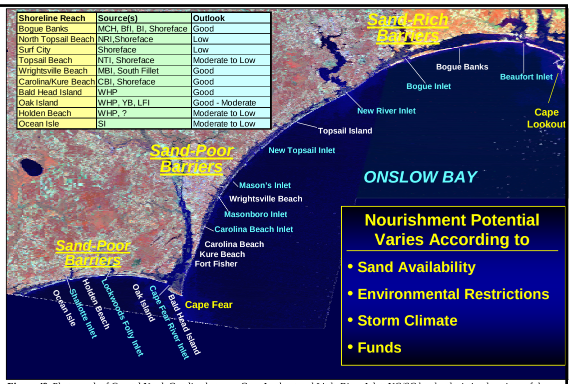


Figure 48. Aerial photographs of Sunset Beach, Bird Island, Mad and Tubbs Inlets. **A.** View (2002) of the shoreline between Bird Island and Ocean Isle. Note the width of the barrier and the shape of the recurved dune lines. Sunset beach is the only barrier in the area that has prograded naturally. Note the location of inlet in 1970 (blue arrow). **B.** West view (10/12/96) depicting the curvature of the shoreline between Tubbs Inlet and Little River Inlet Jetties. Note the migration and welding of swash bars along Sunset beach. The inlet has migrated eastward since relocation in 1970 –opposite its historic migration direction. **C**. East view (9/17/99) of the closure zone of Mad Inlet that closed in 1998. Inlet closure resulted in the lengthening of the oceanfront. This scenario is the modern day analogue of the closure of all inlets in the Brunswick Co. barrier system where shoreline reaches characterized by parabolic dunes are connected by relatively narrow barrier segments.



Shoreline Reach	Source(s)	Outlook
Bogue Banks	MCH, BfI, BI, Shoreface	Good
North Topsail Beach	NRI,Shoreface	Low
Surf City	Shoreface	Low
Topsail Beach	NTI, Shoreface	Moderate to Low
Wrightsville Beach	MBI, South Fillet	Good
Carolina/Kure Beach	CBI, Shoreface	Good
Bald Head Island	WHP	Good
Oak Island	WHP, YB, LFI	Good - Moderate
Holden Beach	WHP, ?	Moderate to Low
Ocean Isle	SI	Moderate to Low

Figure 49. Photograph of Coastal North Carolina between Cape Lookout and Little River Inlet, NC/SC border depicting locations of the barriers, mainland beaches, inlets and forelands. Insert lists developed reaches and outlook (sand resource potential for nourishment). MCH = Morehead City Harbor, BfI = Beaufort Inlet, Bogue Inlet, NRI = New River Inlet, NTI = New Topsail Inlet, MBI = Masonboro Inlet, CBI = Carolina Beach Inlet, WHP = Wilmington Harbor Project, YB = Yellow Banks, LFI = Lockwood's Folly Inlet SI = Shallotte Inlet. The shoreface sand resources includes paleo-channels (Bogue Banks [unproven] and Carolina/Kure Beaches {proven]) and depressions within geologic units such as those off Topsail Island.