THE INFLUENCE OF INLET MODIFICATIONS, GEOLOGIC FRAMEWORK, AND STORMS ON THE RECENT EVOLUTION OF MASONBORO ISLAND, NC

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ABSTRACT

Masonboro Island is a 13 km long undeveloped barrier island located within a sand deficient southwestern portion of Onslow Bay. The island is situated along major storm tracks and is chronically impacted by tropical and extra-tropical storm events (HOSIER and CLEARY, 1977). The response of the island to storms is a function of the pre-storm condition of the island, the lack of sand in the offshore environment, the influence of adjacent inlets, and the underlying geology (CLEARY *et al*., 1999). Masonboro Island provides an exemplary setting to study changes in barrier island morphology and shoreline change in response to inlet modifications, geologic framework, and storm impact because the island is undeveloped, remains relatively unnourished, and is flanked by two modified inlets.

A GIS based study utilizing aerial photography was used to ascertain shoreline change occurring during 1938 – 2002. The island was divided into a northern, central, and southern segment based on distinct erosional characteristics. Masonboro Island experienced island wide erosion during the 64-year study period. The northern segment, which includes the fillet adjacent to Masonboro Inlet, eroded an average distance of 43 m. The central segment had net shoreline erosion of 110 m, while an area of shoreline within the central reach that was perched on a paleo-interfluve eroded only 106 m. The greatest amount of shoreline change was 164 m of erosion, which occurred along the southern segment of the island adjacent to Carolina Beach Inlet.

Short-term analysis (1.3 yr.) of a 2.5 km section of the island/estuary related the influence of a small Pleistocene interfluve to morphological changes within the area.

Vibracore data from the estuary behind this area indicate that the Holocene fill is relatively shallow and ranged in thickness from greater than 4 m over the infilled valleys to less than 1.5 m over the interfluves. The network of interfluves extends from the mainland, beneath the estuary, and is overridden by the island. Survey data indicate that the shoreline perched on the interfluve was restricted to ~17 m of erosion compared to an average of ~30 m to either side. The profile of this entire section was lowered in elevation, and approximately 53,000 m^3 of material were removed from the area.

The lowered profile made this section of the island increasingly vulnerable to overwash. The coarse grained nature of existing washover fans prevented the regrowth of new dunes. Petrologic analyses indicated that the source of the coarse grained material was a sandy limestone found along the shoreface of the southern two-thirds of the island. Further analyses indicated that the limestone was similar in nature to the coquina facies of the Neuse Formation intermittently exposed in the region.

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INTRODUCTION

The need to understand processes related to barrier island evolution and the rapidity of shoreline change is becoming increasingly important as a result of an increased demand for ocean-front property and the need to protect these coastal investments. The southeastern coast of North Carolina is no exception, thus it is critical to understand how North Carolina barrier islands are influenced by natural and anthropogenic factors. Most of the retrograding barriers in southwest Onslow Bay are developed and are repeatedly renourished; consequently it is difficult to assess long-term recession rates and long-term storm impacts on island morphology. Exceptions do exist and include Masonboro Island, a 13 km long undeveloped island located along the southwestern portion of Onslow Bay. This study focuses on the integrated effects of major storm events, inlet modifications, geologic framework, and recent shoreline changes on the evolution of Masonboro Island.

Study Area and Background

Study Area

Onslow Bay is located along the southeastern coast of North Carolina between Cape Lookout and Cape Fear, and is underlain by geologic units that range in age from Upper Cretaceous to Pliocene (SNYDER *et al*., 1994) (Figure 1). The shoreface sediment cover in this area is usually thin (<1.0 m), and this sediment deficiency is a result of low fluvial

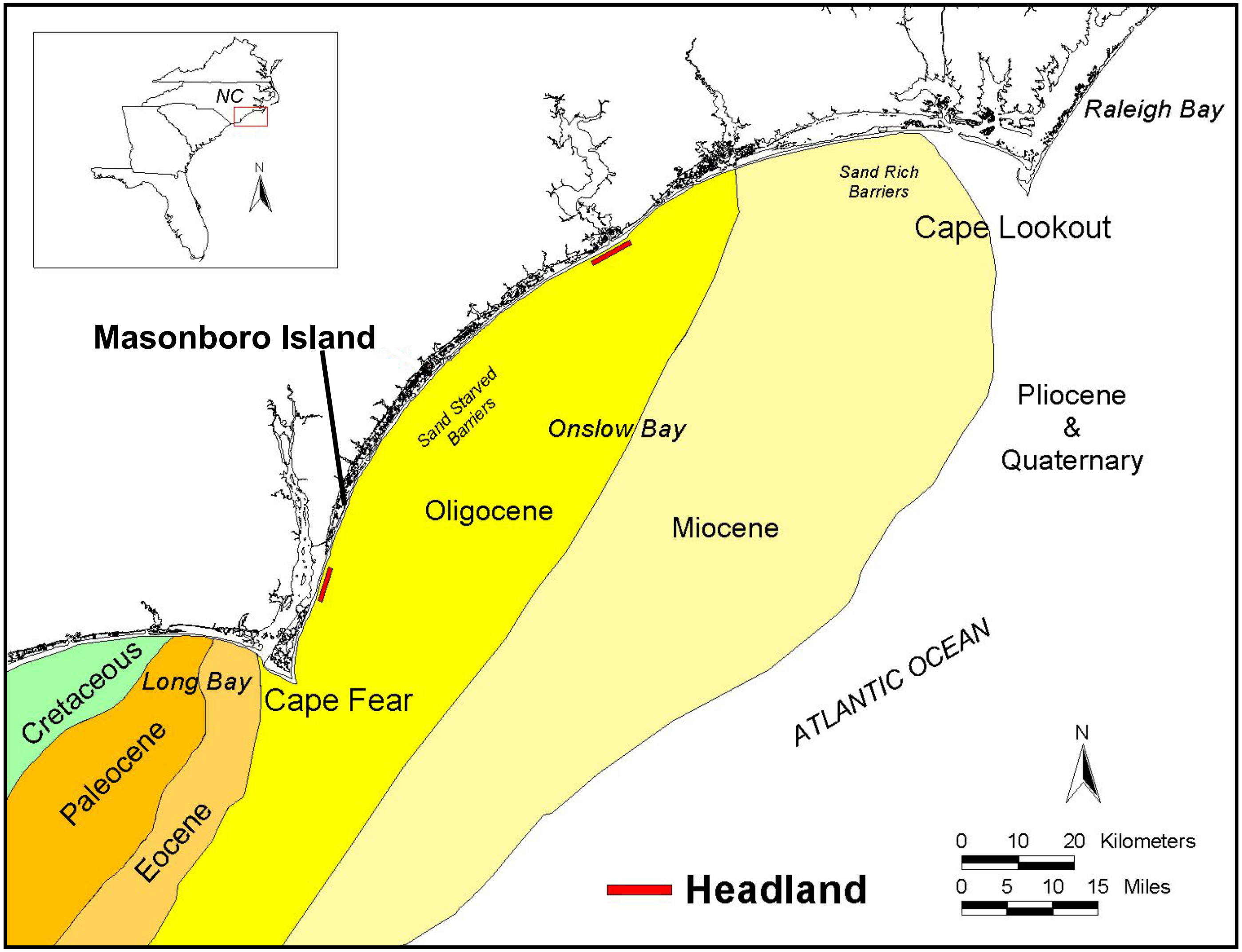

Figure 1. Regional geologic setting of Southeastern North Carolina (After SNYDER *et al*., 1982).

input and the lack of sediment exchange with adjacent Long Bay and Raleigh Bay (CLEARY and PILKEY, 1968 and RIGGS *et al*., 1995).

Masonboro Island is a 13 km long undeveloped barrier island located within the wave dominated, low-mesotidal environment of southwestern Onslow Bay (Figure 2). JARRETT (1977) reports that mean significant wave heights in this area are 0.78 m and the typical wave period is 7.88 s. Masonboro Inlet forms the northern border of the island and is stabilized by a dual jetty system. The weir jetty on the north side of the inlet was completed in 1966, while construction of the rock jetty along the southern margin of the inlet was completed in 1981. Carolina Beach Inlet forms the southern boundary of the island and separates Masonboro Island from Carolina Beach. Masonboro Island was contiguous with Carolina Beach until the inlet was artificially opened in 1952. Modifications of these inlets have significantly reduced the littoral drift. A report published by the United States Army Corps of Engineers (USACE, 2000) states that between 1969 and 1999 the estimated sediment deficit along Masonboro Island was ~2.4 million cubic meters. The reduced sand supply was primarily due to the entrainment of sand within the inlet systems and secondarily due to sea level rise.

Masonboro Inlet is a federally maintained inlet that is used as a source of nourishment material for adjacent beaches (Figure 3A). The transport of littoral sediment to the south passes over the northern weir jetty, at which point it is captured by the inlet channel and deposited in the flood and ebb tidal deltas. Dredged material removed from the inlet system is generally placed along developed Wrightsville Beach; however, in 1986, 1994, and 1998 a cumulative amount of 1,541,800 cubic meters of sediment was placed along the northern section of Masonboro Island (USACE, 2000). The design of the rock jetty

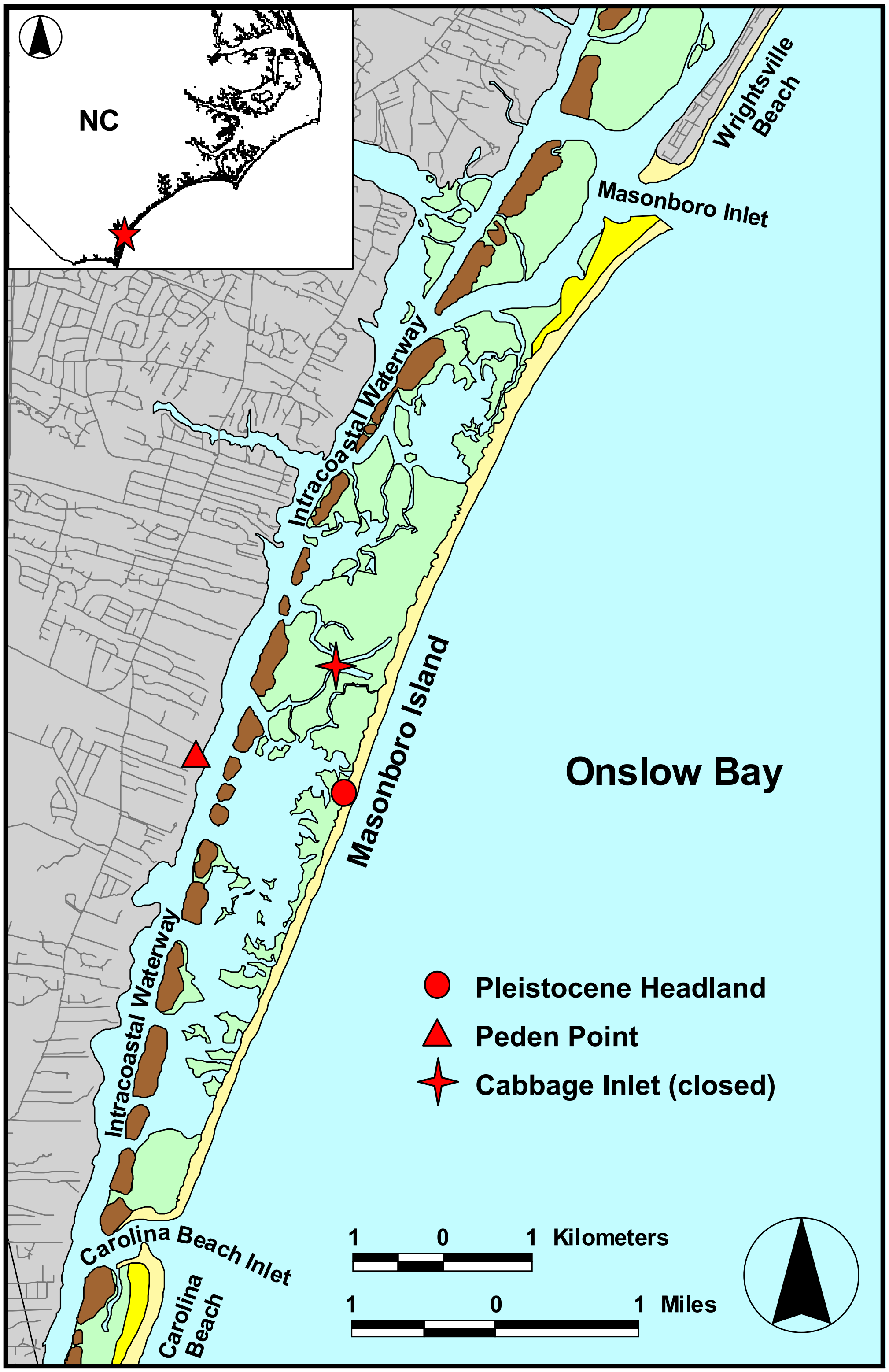

Figure 2. Location map of Masonboro Island, NC.

Figure 3. (A) Masonboro Inlet – the north jetty was completed in 1966 and the south jetty was completed in 1981. Note the impoundment of sand comprising the fillet adjacent to the south jetty. (B) Carolina Beach Inlet – this inlet was artificially opened in 1952 and must be repeatedly dredged to prevent closure. Photographs courtesy of William J. Cleary.

along the south side of the inlet practically stops all sediment moving north in the littoral system from passing the jetty. As a result, a fillet (an accretionary wedge of sand deposited by waves and littoral transport adjacent to a jetty or groin) developed at the north end of Masonboro Island since the completion of the jetty in 1981.

Carolina Beach Inlet, which is also federally maintained, was opened in 1952 at the request of fishing enthusiasts in the area (Figure 3B). Prior to 1952, Masonboro Island was contiguous with Carolina Beach and had a relatively stable shoreline. After opening, the inlet immediately began to capture littoral sediment, and as a result the shoreline adjacent to the inlet eroded in excess of 300 m within the first 11 years after the inlet was opened (USACE, 2000). In 1967, a sediment trap was dredged in the inlet to serve as a renewable borrow source for nourishment material for Carolina Beach to the south (USACE, 2000). The placement of beach material along Carolina Beach partially mitigated the sediment deficit in that area; however, the sediment deficit significantly increased along the southern portion of Masonboro Island. The first use of the sediment trap material for renourishment purposes was in 1971. Subsequent removal of sediment occurred in 1981, 1985, 1988, 1991, 1995, and 1998. The opening of Carolina Beach Inlet and the completion of the north and south jetties along Masonboro Inlet severely altered the sediment budget for Masonboro Island (USACE, 2000).

Local Geology

The shoreface off of Masonboro Island is geologically complex and consists of poorly consolidated Oligocene siltstone, well-lithified Oligocene and Plio-Pleistocene limestones, along with Pleistocene calcarenite subcrop units that are frequently exposed on the sea floor along the southern portion of the island. CLEARY *et al*. (1993) found that sections of the shoreface are characterized by low relief scarps and ridges underlain by Oligocene dolosilt and Plio-Pleistocene limestone and high relief scarps and ridges underlain by Pleistocene calcarenite. These hardbottoms are often covered by thin patches of sediments (<1 m). Fine quartz sands dominate sediments on the northern shoreface while the remainder of the shoreface sediment is composed of coarse orange-brown to gray shell hash with variable amounts of quartz sand and pebbles (CLEARY *et al*. 1999). The fine quartz sands and the coarse shell hash are produced by the degradation of the dolosilt and calcarenite, respectively. The Pleistocene calcarenite is intermittently exposed along the southern portion of the island. CLEARY *et al*. (1999) also refers to the calcarenite as a coquina and indicated that the coquina hardbottoms tend to form low-relief irregular scarps along the landward portion of the shoreface, and these scarps entrain seaward moving sediment potentially removing the sediment from the littoral system. The breakdown of the coquina provides the source material for the majority of the coarse sand and shell hash on the island, and this material is similar in composition to local exposures of the Neuse Formation described by DOCKAL (1996) and MARCY (1999). For narrative purposes, the term coquina will be loosely used to describe the partially to well-indurated sandy limestone facies of the Nuese Formation throughout the remainder of the text.

The island is relatively narrow, low-lying, and prone to frequent overtopping. Thus, overwash events have played an important role in the evolution of Masonboro Island. Previous storm events have pushed large volumes of washover sediments across the low-lying barrier island (MOUNDALEXIS, 1998). CLEARY and HOSIER (1979) state that the coarse grained nature of the washover sediments inhibits the formation of new dunes. The deflated portions of the washover fans consist of an armor of coarse shell hash and gravels that are not capable of aeolian transport. Furthermore, the coarse grained nature of the fans does not have the water holding capacity that is necessary for colonization by herbaceous vegetation. Consequently, the dunes are not rebuilding, and frequent overwash events easily transport material into the adjacent lagoon.

Inlets have also played an important but variable role in the evolution of Masonboro Island. Vestiges of old inlet systems are still recognizable by relict flood deltas preserved in the estuary including Cabbage Inlet, which was briefly open during the 18th Century (Figure 4). CLEARY and HOSIER (1979) indicate that inlets have influenced between 60 and 70% of the length of Masonboro Island over the last several centuries, and these inlet influences were a major control on the nature of the sediments deposited in the lagoon.

Masonboro Island is backed by a 1.5 km wide marsh-filled lagoon that separates the island from the mainland. CLEARY and HOSIER (1994) state that the onset of estuarine sedimentation began about 4,100 years B.P. and describe five main estuarine sedimentalogical facies that include (1) coarse grained overwash, (2) fine grained outwash, (3) marsh or peat, (4) mud-flat complexes, and (5) tidal creek deposits. The Holocene fill overlies Pleistocene age sediments that range from variegated compact mud to coarse sand and carbonate gravel (CLEARY and HOSIER, 1994).

The entire island is currently eroding except for the shoreline along the fillet directly adjacent to the jetty at the north end of the island. The North Carolina Division of Coastal Management (NCDCM, 1998) indicated the average annual erosion rate for

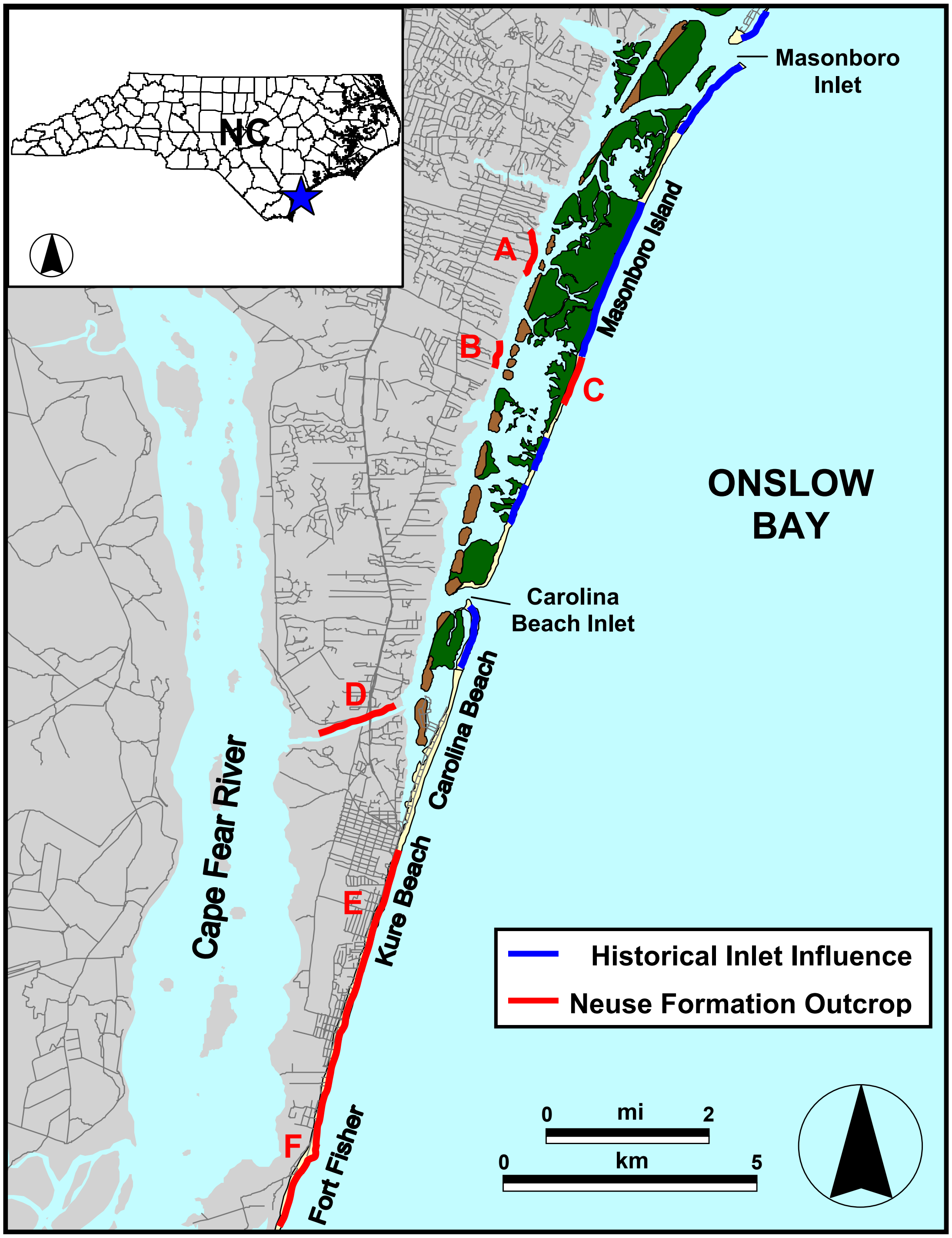

Figure 4. Map of Lower Cape Fear River indicating influence of historic inlets and past and current exposures of Neuse Formation. (A) Semi-indurated humic-rich facies at Friendly Lane. (B) Exposure of lithified calcarenite facies at Peden Point. (C) Semi-indurated humic-rich facies exposed after Hurricane Fran. (D) Intermittent exposures of lithified and unlithified calcarenite and humic-rich facies at Snow's Cut. (E) Semi-indurated humic-rich facies exposed after Hurricane Fran. (F) Lithified calcarenite facies exposed stratigraphically lower than humic-rich facies.

Masonboro Island ranged from nearly 4 m/yr along the south end of the island to less than 0.5 m/yr along the north end. Generally, the island is classified as a transgressive barrier that has extensive exposures of estuarine mud and peat commonly outcropping along the southern section of the island (HOSIER and CLEARY, 1977; CLEARY and HOSIER, 1979; SAULT *et al*., 1999). The mud and peat represent sediment facies that are easily eroded during high-energy events. In addition, a significant portion of the island is underlain by channel or inlet fill material that is also easily eroded. CLEARY and HOSIER (1994) indicate that inlet fill material underlies approximately 65% of the island. Some sections of the barrier are inherently more resistant to erosion due to changes in the underlying geology. A portion of the shoreline located near the center of the island is influenced by a small submarine headland where the beach is likely perched on a paleo-interfluve. The small paleo-interfluve is believed to extend from Peden Point 1km east where it is truncated by the shoreface (Figure 2) and likely formed during drainage development when sea level was lower (CLEARY *et al*., 1999).

The interfluve is a semi-consolidated stratigraphic unit that is resistant to erosion. The small headland is composed of a Pleistocene humate sandstone/coquina sequence and is believed to extend beneath the island, estuary, and mainland (CLEARY *et al*., 1999; SAULT *et al*., 1999). CLEARY *et al*. (1999) observed that historical overwash was less extensive in the vicinity of the paleo-interfluve in comparison to the adjacent transgressive portions. SAULT *et al*. (1999) also suggested that the headland would act as a hinge on which the southern segment of the island would ultimately pivot.

Similar sequences of sandstone and coquina are exposed in several other areas to the south of Masonboro Island (Figures 4-7). The coquina in the vicinity of Fort Fisher, NC

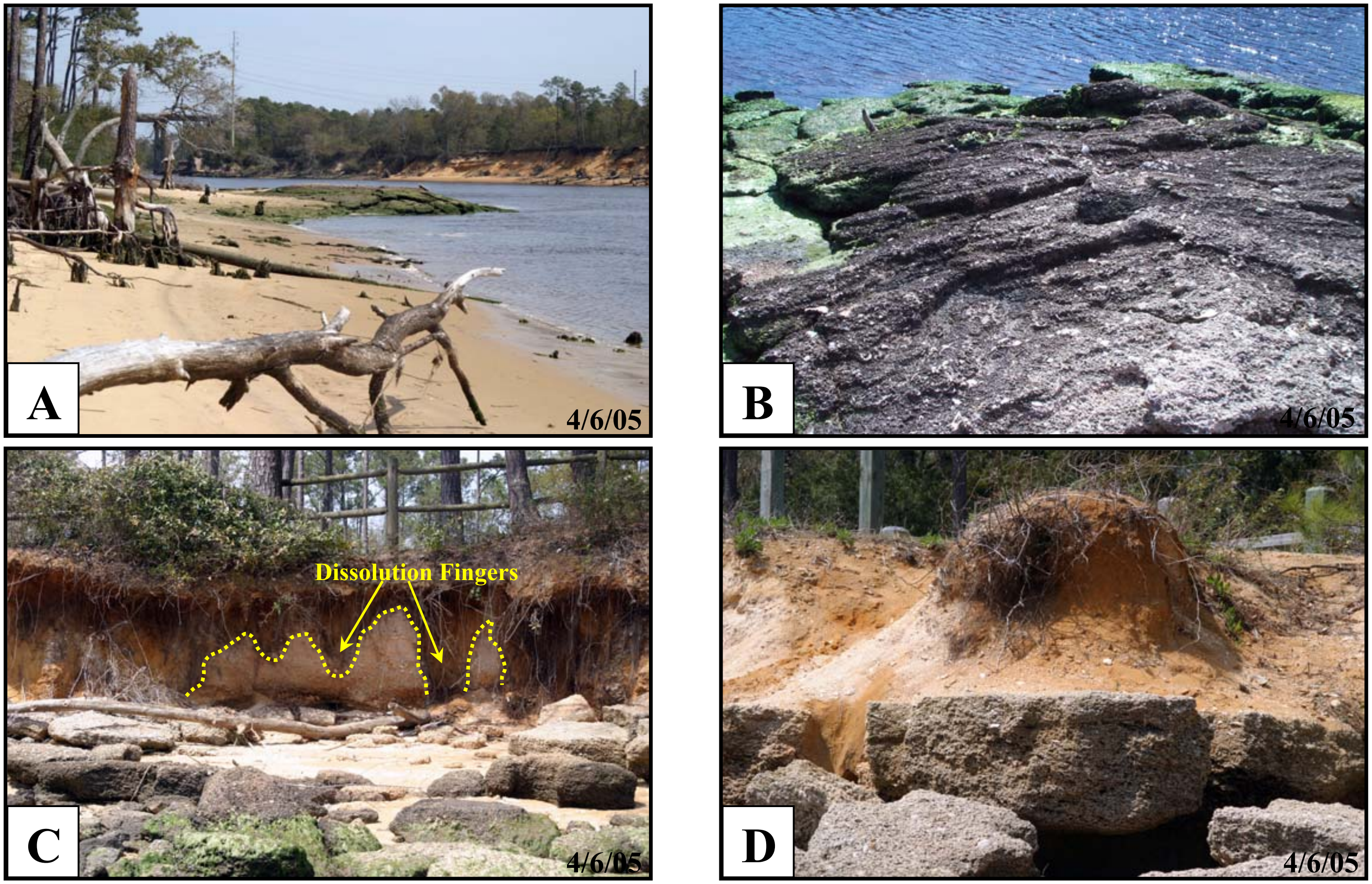

Figure 5. Coquina facies of the Neuse Formation located at Snow's Cut (Figure 4D). (A) East view of well-lithified coquina extending into the waterway. (B) Close-up view of well-lithified coquina with visible bedforms. Field of view is ~2 m. (C) Poorly lithified coquina with visible dissolution fingers. (D) Poorly lithified coquina overlying well-lithified coquina. Dockal (1996) associates the lithified portion of the coquina with the uppermost level of a paleo-watertable. Photographs courtesy of William J. Cleary.

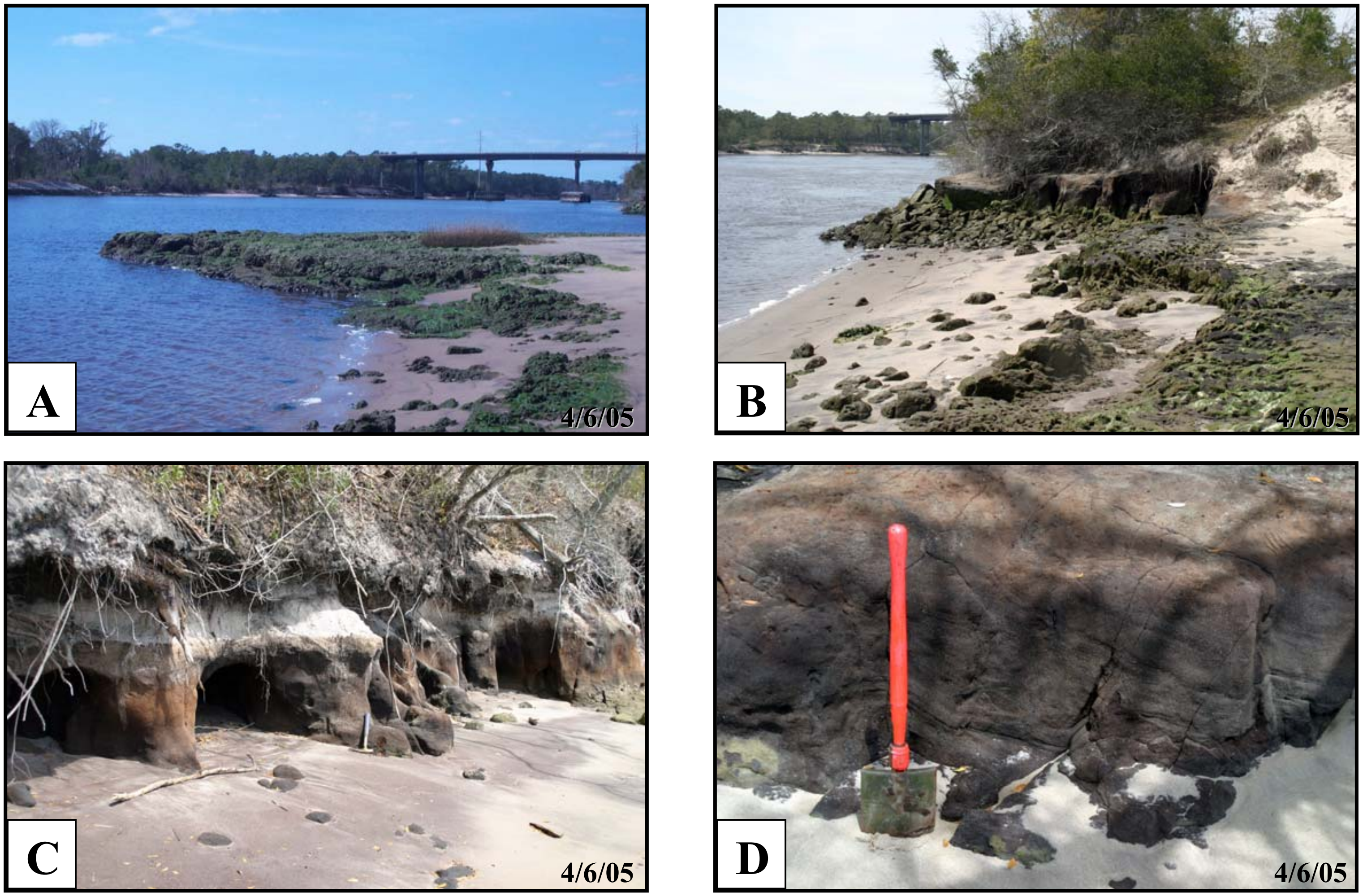

Figure 6. Humic-rich friable sandstone facies of the Neuse Formation (locally known as Kure Beach Sandstone) located at Snow's Cut (See Figure 4D). (A) West view of sandstone platform extending into waterway. (B) West view of sandstone outcrop exposed along waterway. (C) Steep bank formed by humate sandstone. Bank is ~1 m in height. (D) Close-up view of humate sandstone with visible sedimentary structure. Photographs courtesy of William J. Cleary.

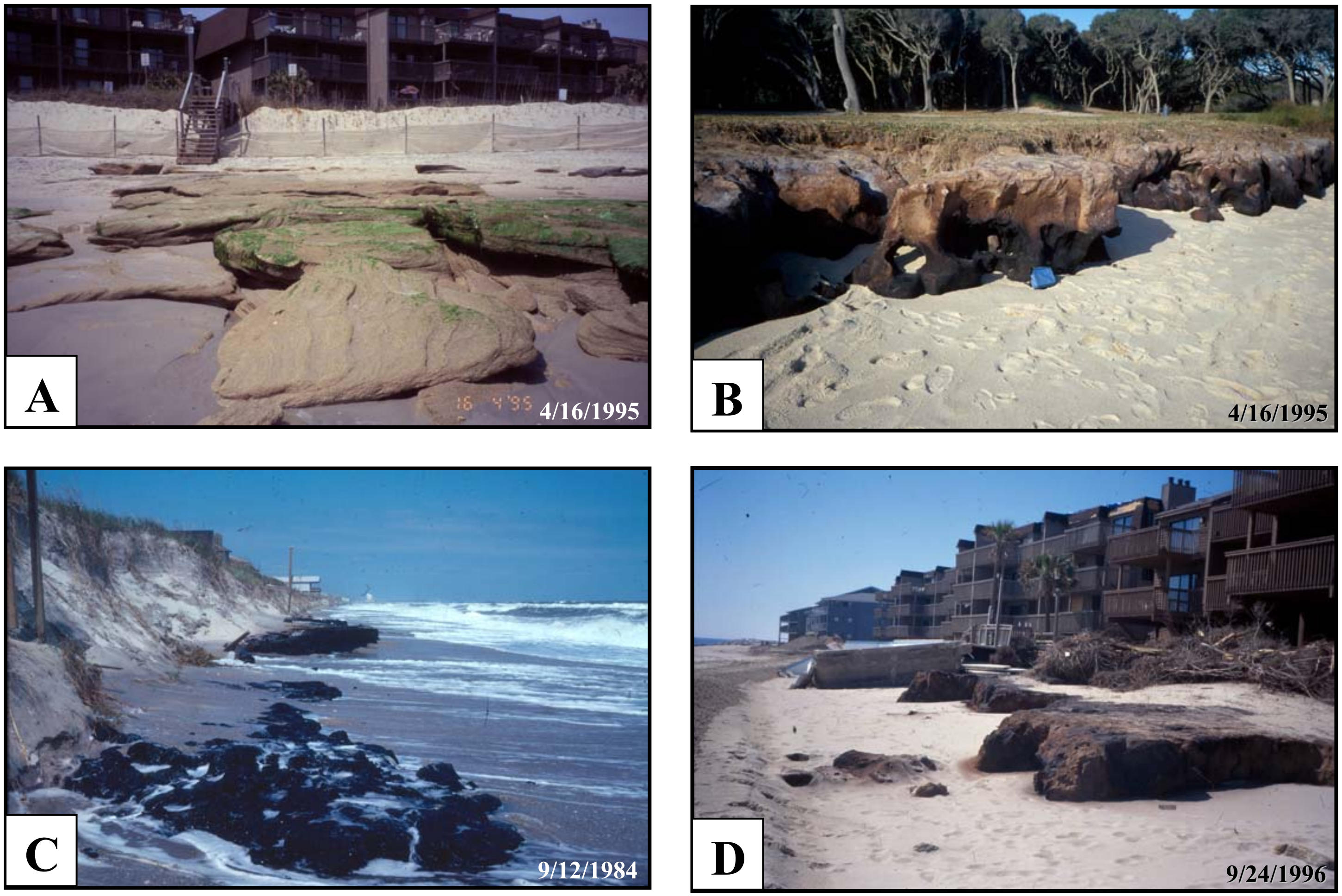

Figure 7. Images of Neuse Formation exposures along Fort Fisher and Kure Beach (Figure 4E and 4F). (A) Lithified coquina within the intertidal zone near Fort Fisher. (B) Friable humate sandstone at Fort Fisher locally known as Kure Beach Sandstone (KBSS). (C) Friable humate sandstone (KBSS) at Kure Beach exposed within intertidal zone. Image was taken 2 weeks after Hurricane Fran (9/5/1996). (D) Humate sandstone platform (KBSS) exposed along Kure Beach following the impact of Hurricane Fran in 1996. Photographs courtesy of William J. Cleary.

has been the subject of numerous papers over the years (STEPHENSON, 1912; WELLS, 1944; FALLOW and WHEELER, 1969; FALLOW, 1973; DOCKAL, 1996) and is generally described as a medium to coarse grained fossiliferous sand or limestone with varying degrees of cementation (DOCKAL, 1996). WELLS (1944) described the coquina along with the Carolina Beach Sandstone, which is a thick, humic-rich friable sandstone in the area of Kure and Carolina Beaches. DOCKAL (1996) states that the humic-sandstone and coquina are both members of the Neuse Formation. Cursory observations indicate that the differences between these two facies are due to varying degrees of the dissolution of carbonate material and the accumulation of varying amounts of translocated humic material. Portions of the Neuse Formation are sporadically exposed along New Hanover and Brunswick County shorelines and represent sections of the geologic framework that are resistant to erosion. The resistance to erosion along these reaches of shoreline is evident in the morphology of these beaches.

Storm History

Masonboro Island is situated along major storm tracks and is frequently influenced by tropical and extra-tropical storms (Table 1). Numerous hurricanes, some major, have impacted the southeastern coast of North Carolina since 1938 (Figure 8). BARNES (1998) described the hurricane history of North Carolina, including storms that had a significant impact on the coast in the vicinity of Masonboro Island. On August 1, 1944, an unnamed category 1 hurricane made landfall at Southport, NC. The hardest hit section of the coast was immediately south of Masonboro Island at Carolina Beach where waves

Date	Name	Wind Speed (kts)	Wind Speed (mph)	Pressure (mb)	Category
-					-
10/24/1938	NOT NAMED	40	45	0	E
8/1/1944	NOT NAMED	80	90	990	H1
6/25/1945	NOT NAMED	60	70	0	TS
7/6/1946	NOT NAMED	40	45	0	TS
9/27/1953	FLORENCE	35	40	0	E
10/15/1954	HAZEL	110	125	937	H3
8/17/1955	DIANE	60	70	986	TS
9/26/1956	FLOSSY	30	35	0	E
9/27/1958	HELENE	115	135	938	H4
7/30/1960	BRENDA	50	60	0	TS
9/12/1960	DONNA	95	110	958	H2
9/14/1961	NOT NAMED	30	35	0	TD
9/13/1964	DORA	45	50	0	TS
6/12/1968	ABBY	25	30	0	TD
10/20/1968	GLADYS	75	85	0	H1
8/17/1970	NOT NAMED	30	35	0	TD
6/21/1972	AGNES	30	35	990	TD
6/28/1975	AMY	25	30	1011	TD
10/27/1975	HALLIE	45	50	1002	TS
9/6/1977	CLARA	25	30	1012	TD
8/20/1981	DENNIS	50	60	999	TS
6/19/1982	SUBTROP1	60	70	992	SS
9/12/1984	DIANA	80	92	949	H2
11/22/1985	KATE	45	50	996	TS
8/8/1987	ARLENE	10	10	1016	L
6/6/1995	ALLISON	40	45	995	E
6/19/1996	ARTHUR	40	45	1005	TS
7/12/1996	BERTHA	90	105	974	H2
9/5/1996	FRAN	100	115	952	H3
10/8/1996	JOSEPHINE	45	50	988	E
8/26/1998	BONNIE	100	115	962	H3
9/16/1999	FLOYD	90	105	950	H2
6/14/2001	ALLISON	25	30	1008	SD
10/12/2002	KYLE	30	35	1012	TD
8/14/2004	CHARLIE	75	85	988	H1

Table 1. List of storms that have come within 100 km of Masonboro Island during the period of 1938 – 2002. Category labels are as follows: L – Tropical Low; E – Extratropical Storm; SD – Subtropical Depression; SS – Subtropical Storm; TD – Tropical Depression; TS – Tropical Storm; H1-H5 – Hurricane Category 1 – 5.

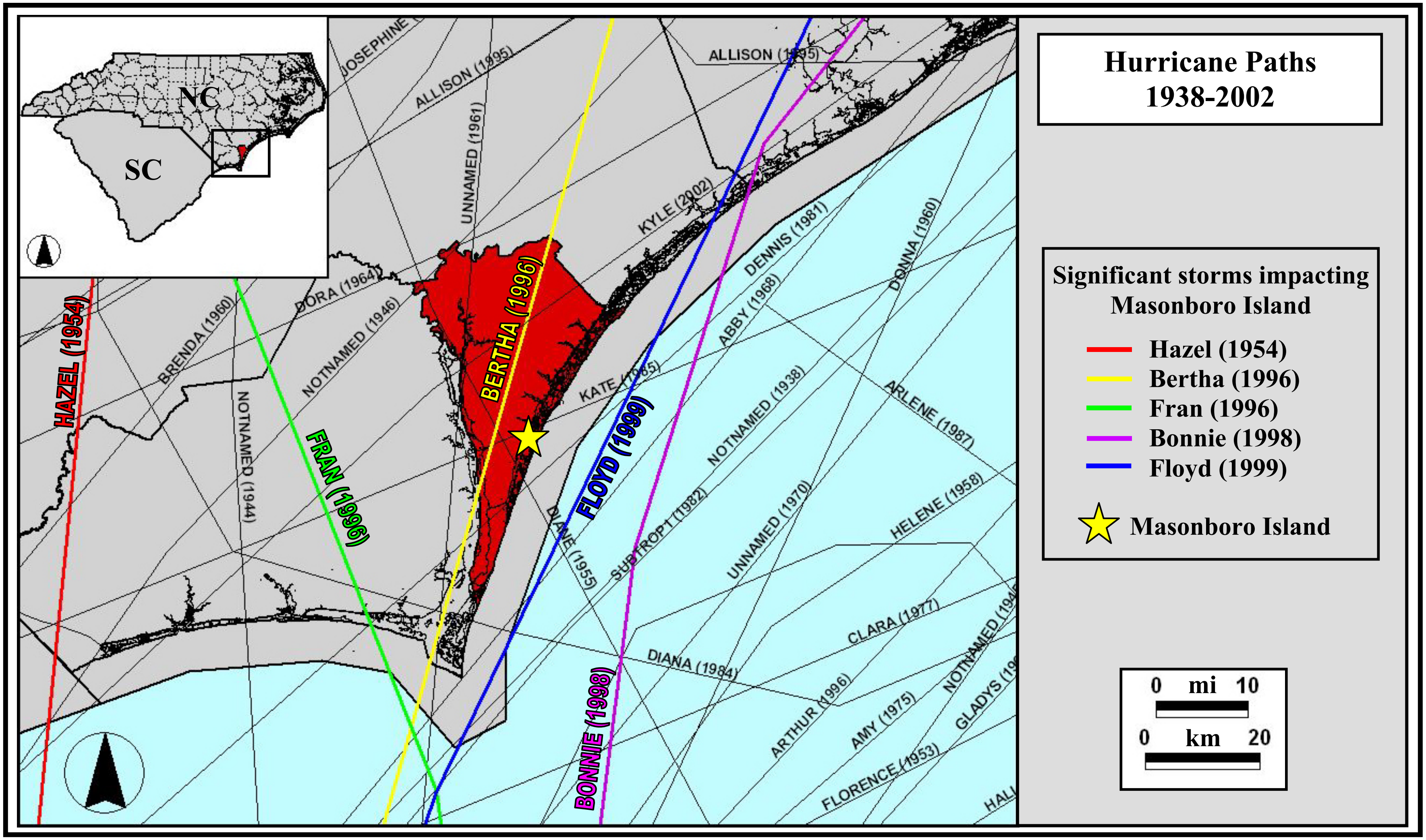

Figure 8. Hurricane paths during the period of 1938 – 2002 that came with in 100 km of Masonboro Island.

were reported as high as 2.7 m. Wave heights were less on the north side of Masonboro Island, but 1.7 m waves were recorded along Wrightsville Beach.

Ten years later, one of the most damaging storms to hit the area was Hurricane Hazel, which made landfall on October 15, 1954 during the highest lunar tide of the year. The storm made landfall along the NC-SC border near Calabash, NC as a Category 3 storm. The hurricane produced a storm surge in excess of 5.5 m (18 ft.) near the northeastern eye wall and a surge greater than 3.5 m (12 ft.) north of Masonboro Island. In addition, wind speeds in excess of 200 km/hr were observed at Wrightsville Beach. In 1955, Hurricanes Connie (August 12), Diane (August 17), and Ione (September 19) struck within a period of five weeks. These storms were only category 1 hurricanes, but the storm surges (1.5-2.5 m) and the brief recovery time between storms combined to produce significant erosion along the island. Hurricane Donna made landfall on September 11, 1960 near Topsail Island, north of Masonboro Island. Storm surge associated with the category 3 storm was about 1-2 m with wind gusts of 155 km/hr recorded in the city of Wilmington. The period between 1960 and 1984 was relatively quiet until Hurricane Diana made landfall on September 9, 1984 near Bald Head Island as a category 2 storm. By the time the storm made landfall, the storm surge was relatively minor (1.5 m at Carolina Beach) and winds had decreased to less than 160 km/hr (BARNES, 1998).

After a brief respite from major storms, Southeastern North Carolina experienced an increase in storm activity with the impacts of Hurricane Bertha on July 12, 1996 and Hurricane Fran on September 5, 1996, which were category 2 and 3 storms, respectively. Hurricane Bertha made landfall at Kure Beach, NC with wind speeds of 150 km/hr, but the intensity of the storm quickly diminished moving away from the eye wall. Hurricane

Fran made landfall further south near Bald Head Island, NC, but the highest storm surge (2.5-3.5 m) was observed immediately north of Masonboro Island (BARNES, 1998).

Two years later Hurricane Bonnie made landfall along Cape Fear, North Carolina on August 26, 1998 and pounded the coast for two days. Storm surge from the category 3 storm approached 3 m and wind gusts in the area were measured at 160 km/hr. The following year Hurricane Floyd also struck the southeastern coast on September15, 1999 with winds as high as 145 km/hr (DEL GRECO and HINSON, 1998).

Most recently, Hurricane Isabel made landfall to the north of Masonboro Island along the Outer Banks on September 18, 2003, and following the August 13, 2004 Florida impact, a weakened Hurricane Charlie struck the coast near the North Carolina – South Carolina border. Both of these storms were relatively insignificant in terms of damage to Southeastern North Carolina (NATIONAL WEATHER SERVICE, 2005).

In addition to hurricanes, extra-tropical storms have also played a significant role in the evolution of Masonboro Island, although these storms generally occur more frequently and with less power than hurricanes. As a result, there are limited amounts of data characterizing the influence of nor'easters along southeastern North Carolina. However, due to the frequency of these storms, one could argue that extra-tropical storms can have similar impacts as that of a hurricane, albeit on a local level. The most notable nor'easter to influence the southeastern coast of North Carolina was the Ash Wednesday Storm (March 7-9, 1962), which had a significant impact on the morphology of Masonboro Island. Even though this was a nor'easter, BARNES (1998) ranks this storm among the worst of all the storms that impacted the area. Another notable nor'easter was the Halloween Storm or the "Perfect Storm" that stalled off the coast between October 30 and November 4, 1991. North Carolina experienced intermittent 35-45 mph winds for 5 days and waves ranging from 3-5 m (NATIONAL WEATHER SERVICE, 2005).

Objectives

Masonboro Island provides an exemplary setting to study barrier island evolution in a sand starved environment for several reasons. The natural response of the island to major storms can be monitored without the influence of extensive human activity because the island is undeveloped and chronically impacted by hurricanes and nor'easters. In addition, both Masonboro Inlet and Carolina Beach Inlet have been extensively altered in recent decades. Subsequently, morphological changes along the island that resulted from inlet modifications provide insights into the complex balance between barrier islands and the adjacent inlets. Furthermore, the island to a large extent remains unnourished, which could otherwise mask changes that occurred along the island. There have also been numerous studies of the island, estuary and offshore environment (HOSIER and CLEARY, 1977; CLEARY and HOSIER, 1979; CLEARY et al., 1993; CLEARY and HOSIER, 1994; MOUNDALEXIS, 1998; CLEARY et al., 1999; SAULT et al., 1999; REIMER, 2004), as well as reports that provide data on dredging activities and the overall sediment budget of the island (USACE, 2000). These data could be used to make better educated decisions about future coastal management issues. The purpose of this research is to characterize the influence of geologic framework, inlet modifications, and storm impacts in relation to changes in barrier morphology and shoreline evolution along Masonboro Island. The major objectives of this study are listed as follows:

- Quantify the amount of shoreline change along the island from 1938 – 2002.

- Evaluate shoreline changes related to storms and inlet modifications.
- Describe the lithology of a Pleistocene interfluve and the overlying Holocene deposits that influence a small segment of the shoreline.
- Quantify the extent and influence of the headland on the shoreline.
- Determine sand volume loss and changes in the barrier profile along a 1.7 km reach in the vicinity of the small headland.
- Provide cursory data on the nature of the coquina gravel fraction found on the beach/washover fans compared with the coquina found at local exposures.

METHODOLOGY

Shoreline Change

Long-term Change

A GIS-based analysis of historic aerial photographs was used to quantify shoreline change between 1938 and 2002. Aerial photographs were obtained from the New Hanover County Department of Geographic Information Systems, the U.S. Army Corps of Engineers, and the Cape Fear Museum. The photos were scanned at a resolution of 500 dpi, rectified using the Image Analysis extension of Arc View 3.2 and geo-referenced to the North Carolina State Plane projection. Although there are many different sets of aerial photographs of the island, the aerial photographs used in this study were selected based on major milestone events that occurred along the island within the aforementioned time period. Historic aerial photographs marking important events in the evolution of the barrier were selected for the years of 1938, 1954 (post Hurricane Hazel), 1962, 1975, 1982, 1993, 1996 (post Hurricane Fran), and 2002 (post Hurricane Bonnie).

CROWELL *et al.* (1991) states that the use of aerial photography at a 1:10,000 scale has potential error of ± 7.6 m (25 ft); however, the actual error is usually much less (JACKSON, 2004).

A digital shoreline of Masonboro Island from each of the controlled photo sets was created by tracing the wet-dry line along the entire island. The wet-dry line represents the highest extent of water along the beach during the most recent tidal cycle and was chosen because it was relatively easy to detect in the aerial photos. The use of the wet-dry line as a shoreline indicator has been used in previous studies examining shoreline change (CROWELL *et al*., 1991; NCDCM, 1998; JACKSON, 2004; and McGINNIS, 2004). This method of determining shoreline position is open to criticism due to the inherent variability in the interpretation of the wet-dry line, but this method is widely used to analyze historical shorelines. ANDERS and BYRNES (1991) indicate a possible error of 4.9 m (16 ft) associated with this method of digitizing shorelines.

An onshore baseline parallel to the digitized shorelines was established to serve as a fixed reference line from which all shoreline changes were determined (Figure 9). Along this baseline, 85 perpendicular transect lines were established for the entire island at a fixed interval of 152.4 meters (500 feet). The SCARPS! (Simple Change Analysis of Retreating and Prograding Systems) extension for Arc View 3.2 was used to determine the intersection of the shorelines with each transect and quantify the amount of change along each transect in reference to the fixed baseline. SCARPS! also produced a suite of statistics, including end point rate (EPR) and linear regression rate (LRR) (DOLAN *et al*., 1991) that were used to describe shoreline change along each transect for each time period. For comparison, these data were plotted against the 1998 annual shoreline

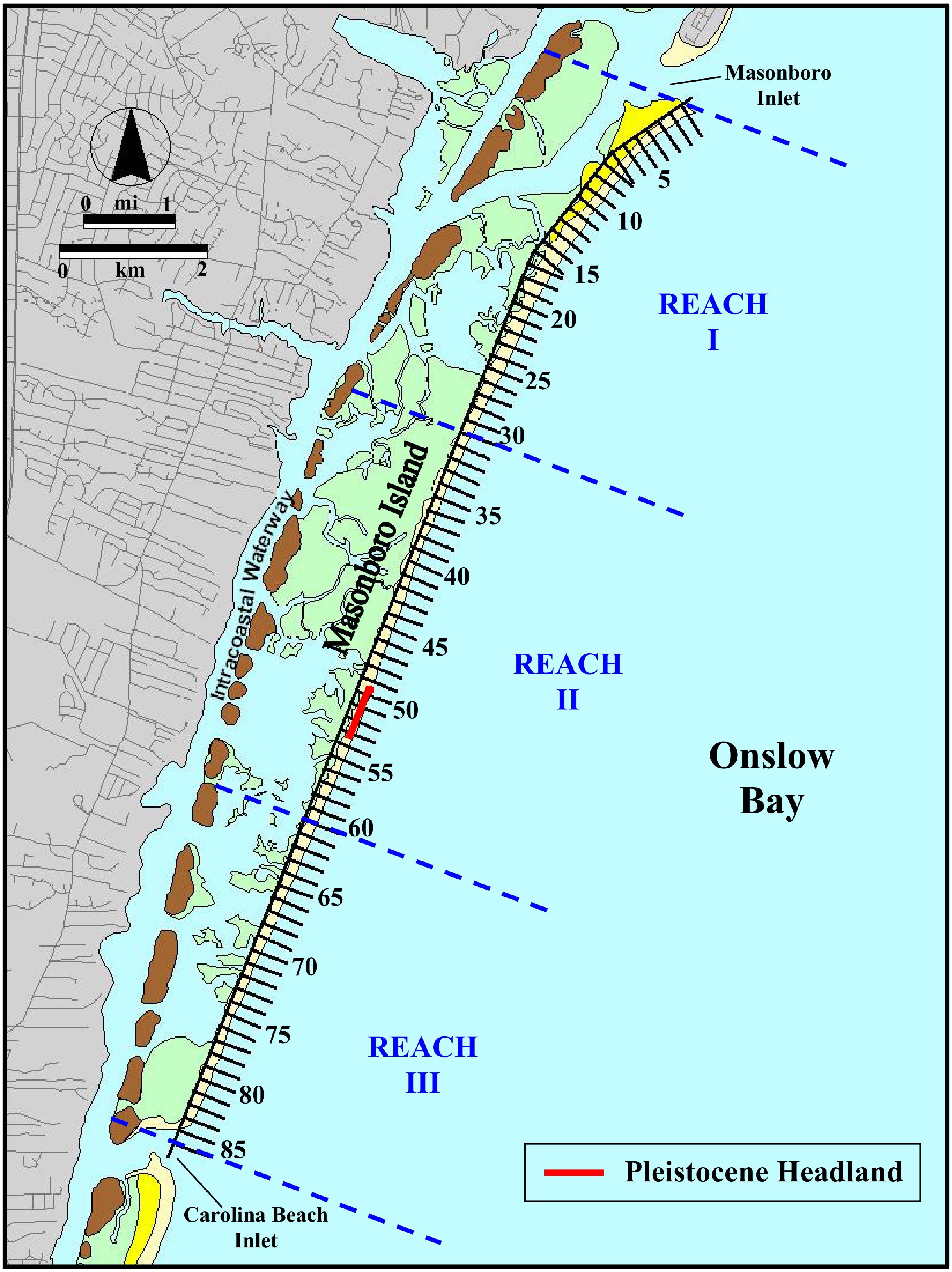

Figure 9. Map of Masonboro Island depicting the baseline and 85 transects used to calculate shoreline change and three reaches used to characterize general changes along the island.

change rates published by the North Carolina Division of Coastal Management (NCDCM, 1998).

Short-term Change

The amount of shoreline change along a 2.5 km section of shoreline, in the vicinity of the small Pleistocene headland, was determined for the period of July, 2003 through November, 2004 (Figure 10). Changes in the shoreline were determined by surveying the wet-dry line in this area with a GPS-based Trimble 5700 RTK (Real Time Kinematic) survey unit periodically (July, 2003; September, 2003; April, 2004; May, 2004; June, 2004; August, 2004, and November, 2004) throughout the study period. The wet-dry line was surveyed in the North Carolina State Plane projection and referenced to the NAD 83 datum and the NAVD 88 datum. A control point for these surveys was established on the roof of the of the Center for Marine Science located three kilometers to the northwest of the study area, and this point was used for each shoreline survey. The control point was obtained by collecting data from the Trimble GPS and submitting it to OPUS, which is a service provided by the NGS (National Geodetic Survey) whereby the GPS data are processed and returned with precise coordinates and elevation (± 2.0 cm). JACKSON (2004) indicated that the total error associated with a GPS-based RTK survey is ± 0.9 m (± 3 ft).

Data from the surveyed wet-dry line were downloaded into Trimble Geomatics Office and then exported to a GIS program (Arc View 3.2). These data were then used to create digital shorelines, from which point shoreline change was calculated using the SCARPS!

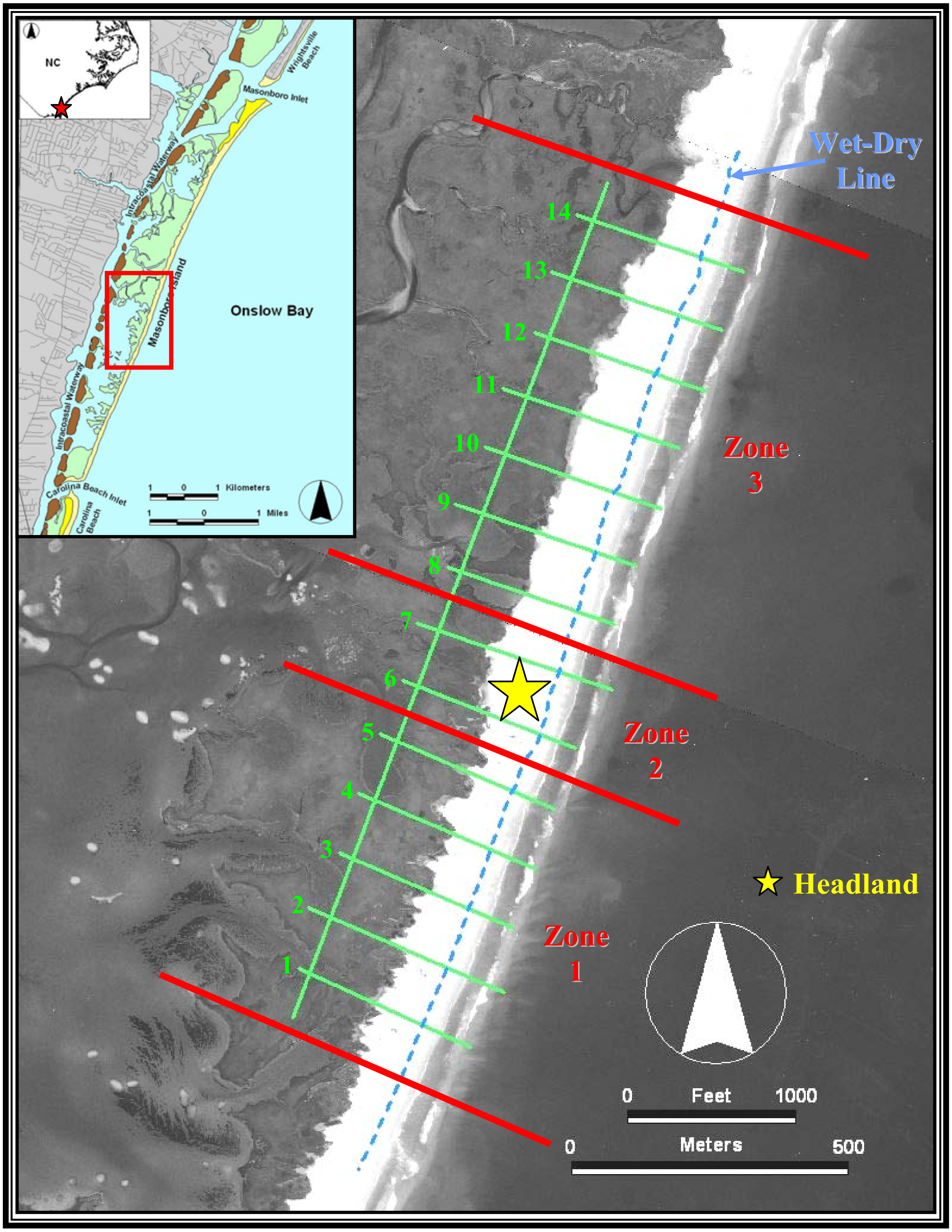

Figure 10. Map of Masonboro Island depicting the 14 transects, three erosion zones and wet-dry line used to characterize general shoreline and profile changes in the vicinity of the Pleistocene headland.

extension of Arc View 3.2 utilizing the same method used to calculate long-term shoreline change.

Volumetric Changes and Profile Changes

Fourteen shore normal transects were established with an interval of 121.9 meters (400 feet) along a 1,706 m (5,600 ft) section of shoreline in the vicinity of the Pleistocene headland (Figure 10). These transects formed the reference lines along which shoreline change rates and volumetric changes were calculated. Once the changes were calculated for each transect the values were utilized to determine the amount of erosion within a cell so that each cell accounted for ~122 m (400 ft) of shoreline. These cells were then grouped into three zones in order to facilitate general determinations about volume losses and profile changes. Zone I included cells 1-5 and covered the region to the south of the Pleistocene headland. Zone II accounted for cells 6 and 7 and was centered along the headland, and Zone III incorporated cells 8-14 and comprised the area to the north of the headland.

Barrier profiles were measured in September of 2003 and in April, May, June, August, and October of 2004 in order to illustrate the change in barrier profile. Each profile was surveyed along one of the 14 transects using the GPS-based survey system also used to measure the wet-dry line. The survey unit measured a point (northing, easting, and elevation) along the transects every 0.5 meters beginning at MHW (mean high water) on the sound side of the island (transition point from intertidal marsh to subaerial beach platform) and extending out to a water depth that exceeded MLW (mean low water) (-

0.59 meters/-1.95 feet) on the ocean side. The profile data were input into an Excel spreadsheet and graphs were made representing the profile changes along each transect.

Profile data from the first and last survey were also used in an application called BMAP 2.0 (Beach Morphology Analysis Package), which is a program created by the U.S. Army Corps of Engineers' Coastal Engineering Research Center to calculate volume losses of sediment over time along selected beach transects. Using this program, the volume of sediment gained or lost along transects and changes in distance along designated contour levels were analyzed. Based on local tidal data from WELSH (2004), contour levels were set as MHW (0.41 meters/1.33 feet), MSL (-0.1 meters/-0.31 feet), and MLW (-0.59 meters/-1.95 feet). The erosion rates of each transect were then applied to the corresponding cell in order to calculate the total volume of sediment gained or lost between September, 2003 and October, 2004. The volume of accretion or erosion within a particular zone was calculated by the summation of volumetric gains or losses of all of the cells within that particular zone.

Shoreline Change Correlative to Storm Impact and Inlet Modification

Shoreline changes and morphological changes along the island during the period of 1938 – 2002 were referenced to the impact of tropical and extra-tropical storms. Changes along the island were also related to the modification of adjacent Carolina Beach and Masonboro Inlets and the nourishment of selected reaches of the island stemming from various modifications made to the inlets. Storm data were retrieved from the NOAA COASTAL SERVICES CENTER (2005) and BARNES (1998), and data pertaining to inlet modifications and nourishment were provided by the U.S. Army Corps of Engineers (USACE, 2000).

Backbarrier Stratigraphy

A suite of 17 vibracores of varying length (6.1 – 9.1 m [20 – 30 ft]) was retrieved from the backbarrier within a 2 km^2 area in the vicinity of the Pleistocene headland (Figure 11). Cores were described on the basis of sediment grain size, color, carbonate sand content, bioturbation and other unique attributes including the depth of the Holocene contact with the underlying Pleistocene unit. The characteristics of the Holocene sediment sequence were used to determine the nature of the depositional environment of the estuary over the last 4,000 years. Similarly, Pleistocene sediment characteristics were used to determine possible depositional environments of the historical landscape, and the depths that the paleo-surface was reached within the cores were used to produce an isopach map of the Holocene unit.

Petrology

A total of eight rock and sediment samples were collected for petrographic analysis. One coquina sample and one poorly cemented humic-sand sample were taken from Snow's Cut where the Neuse Formation is intermittently exposed (Figure 4). An additional sample of the humic-sand was retrieved from the mainland behind the north-central portion of the island at the end of Friendly Lane. Five samples were retrieved from the island in the vicinity of the Pleistocene headland. Three of these were rock samples of coquina boulders found in the intertidal zone, and the remaining samples were sediments recovered from the berm and washover terrace. These samples were

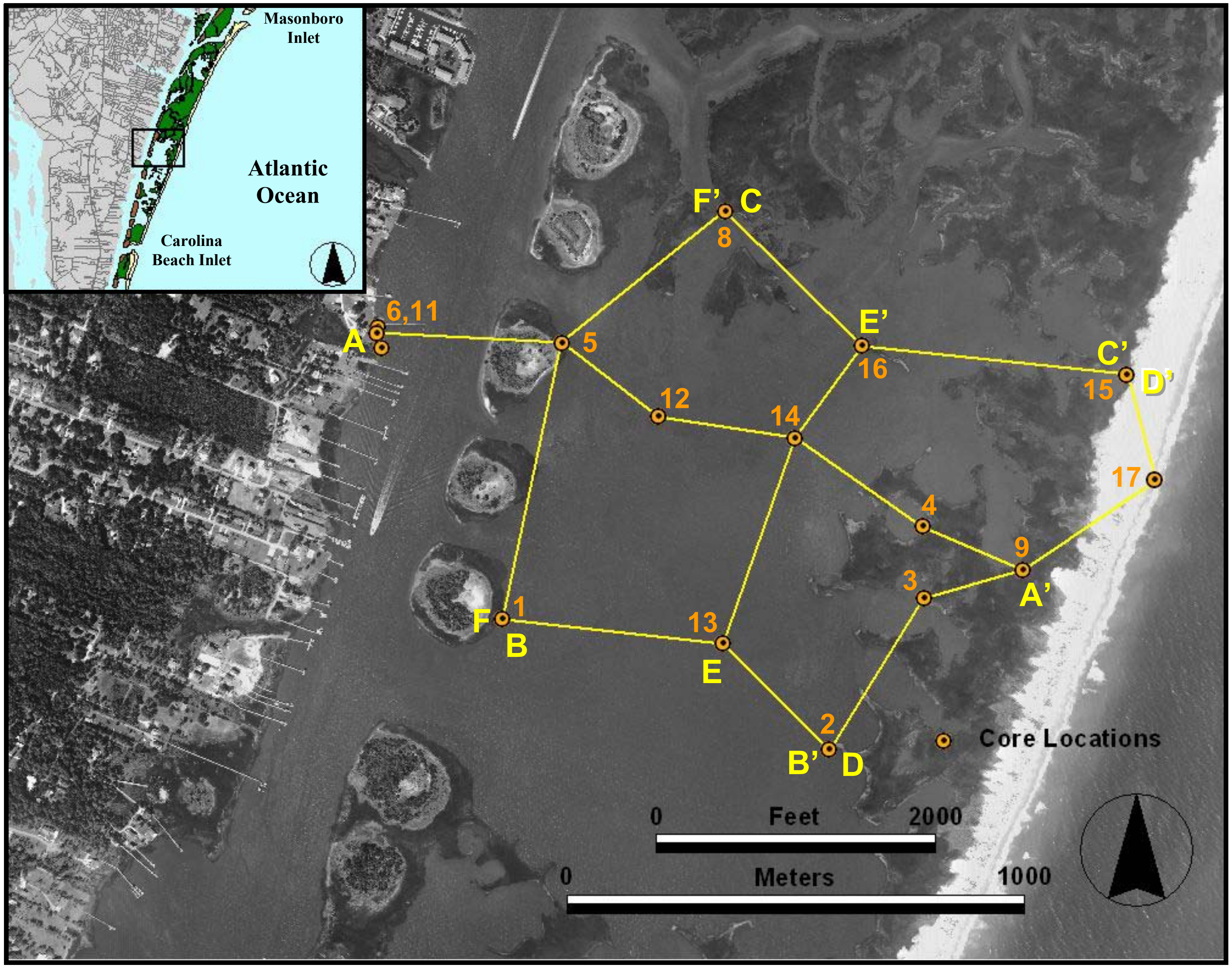

Figure 11. Location of estuarine vibracores and corresponding core transects on 2003 aerial photography.

commercially prepared using vacuum impregnation with blue polyester resin, thin-sectioned, and stained for carbonates. Petrographic analysis of the thin-sections consisted of a 300 point count of the constituent grains, and the rock samples were then classified based on the FOLK (1980) carbonate classification system. The petrology of the calcarenite facies of the Neuse Formation exposed in various localities was compared to samples from large calcarenite boulders found within the intertidal zone in the vicinity of the Pleistocene headland. The comparison was based on mineralogical composition, grain size, and porosity. In addition, the petrology of the lithic fragments found in sediments from the berm and washover fans on the island was compared to boulders of the calcarenite facies. These data, used in conjunction with the percentage of lithic fragments derived from the calcarenite facies, provided an estimate of the source and amount of sediment contributed by near shore lithologies.

RESULTS

Shoreline Change

Long-term Change (1938 – 2002)

For the purposes of this study, Masonboro Island was divided into three different reaches based on contemporary trends in shoreline changes (Figure 9). These reaches are similar to the reaches identified by SAULT *et al*. (1999) and provide a useful way to describe changes along the island. Reach I, which includes transects 1 – 30, is largely influenced by the fillet adjacent to the jetty, consequently this section contains the widest portion of the island (~600 m). The central reach (Reach II) is composed primarily of inlet fill deposited by Cabbage Inlet and other relict but unnamed inlets (RIGGS *et al*., 1995; CLEARY *et al*., 1999). Reach II consists of transects 30 – 60 and is separated from the southernmost reach by a small Pleistocene headland. Reach III covers the southern most portion of the island (transects 60-85) and is underlain primarily by peat and mud with sporadic deposits of inlet and channel fill (RIGGS *et a*l., 1995; CLEARY *et al*., 1999).

All three reaches experienced net shoreline erosion during the period of 1938 – 2002 (Figure 12). The shoreline along Reach I retreated an average distance of 43 m (±15 m) during the 64.2 year period. Net average erosion increased to the south with Reaches II and III translating landward by 110 m (±6 m) and 164 m (±10 m), respectively (Figure 13). Based on these data, the average annual end point rates (EPR) for Reaches I, II, and III were -0.7 m/year (-2.2 ft/year), -1.7 m/year (-5.6 ft/year), and -2.6 m/year (-8.4 ft/year) in that order. The shoreline that straddles a small Pleistocene headland dividing Reach II and III experienced less erosion than the adjacent reaches. Shoreline erosion was limited to 94 m (308.2 ft) throughout the study period or -1.5 m (-4.8 ft) annually. Figure 14 depicts the average annual erosion rates (EPR) and linear regression rates (LRR) along each transect of the island. In addition, these data are plotted against annual shoreline change rates published by the North Carolina Division of Coastal Management (NCDCM, 1998). Because erosion rates varied over time as well as distance, shoreline changes within the three reaches were separated into seven different time periods based on storm history and inlet modification (Table 2).

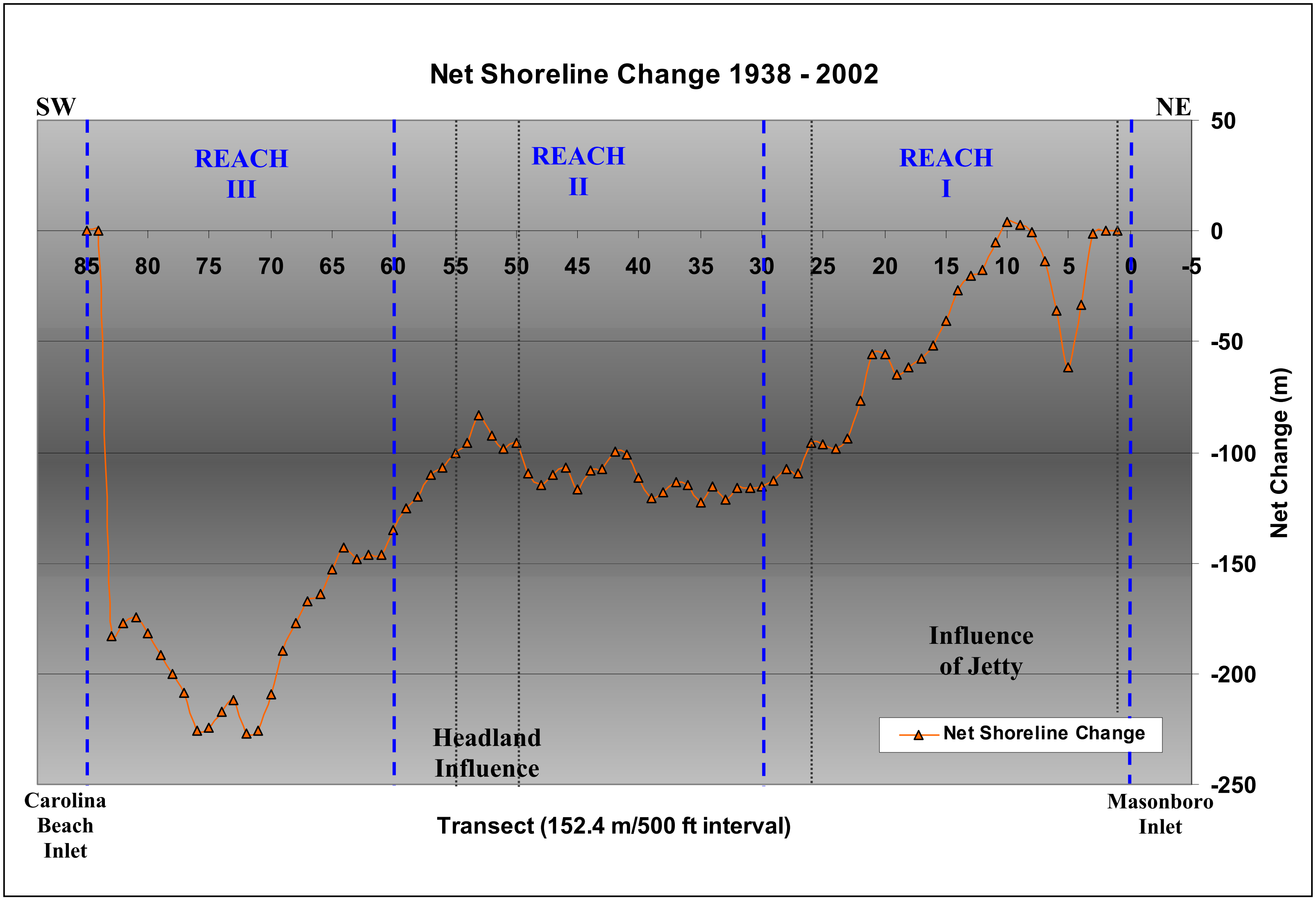

Figure 12. Net shoreline change of Masonboro Island from 1938 - 2002

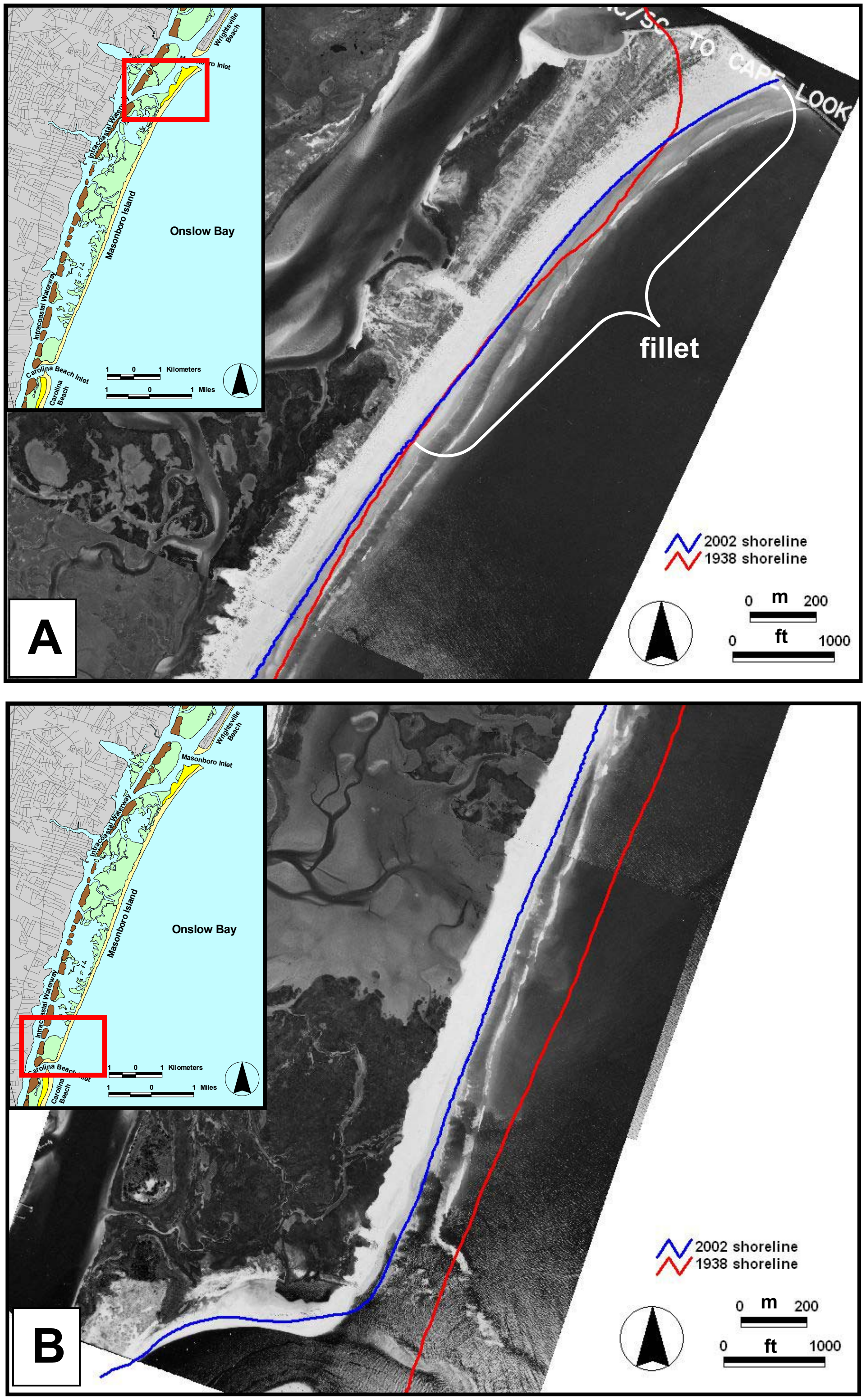

Figure 13. Comparison of 1938 and 2002 shorelines superimposed on 2000 aerial photos. (A) Northern section of island adjacent to Masonboro Inlet. (B) Southern section of island adjacent to Carolina Beach Inlet. Note that the island translated more than one island width.

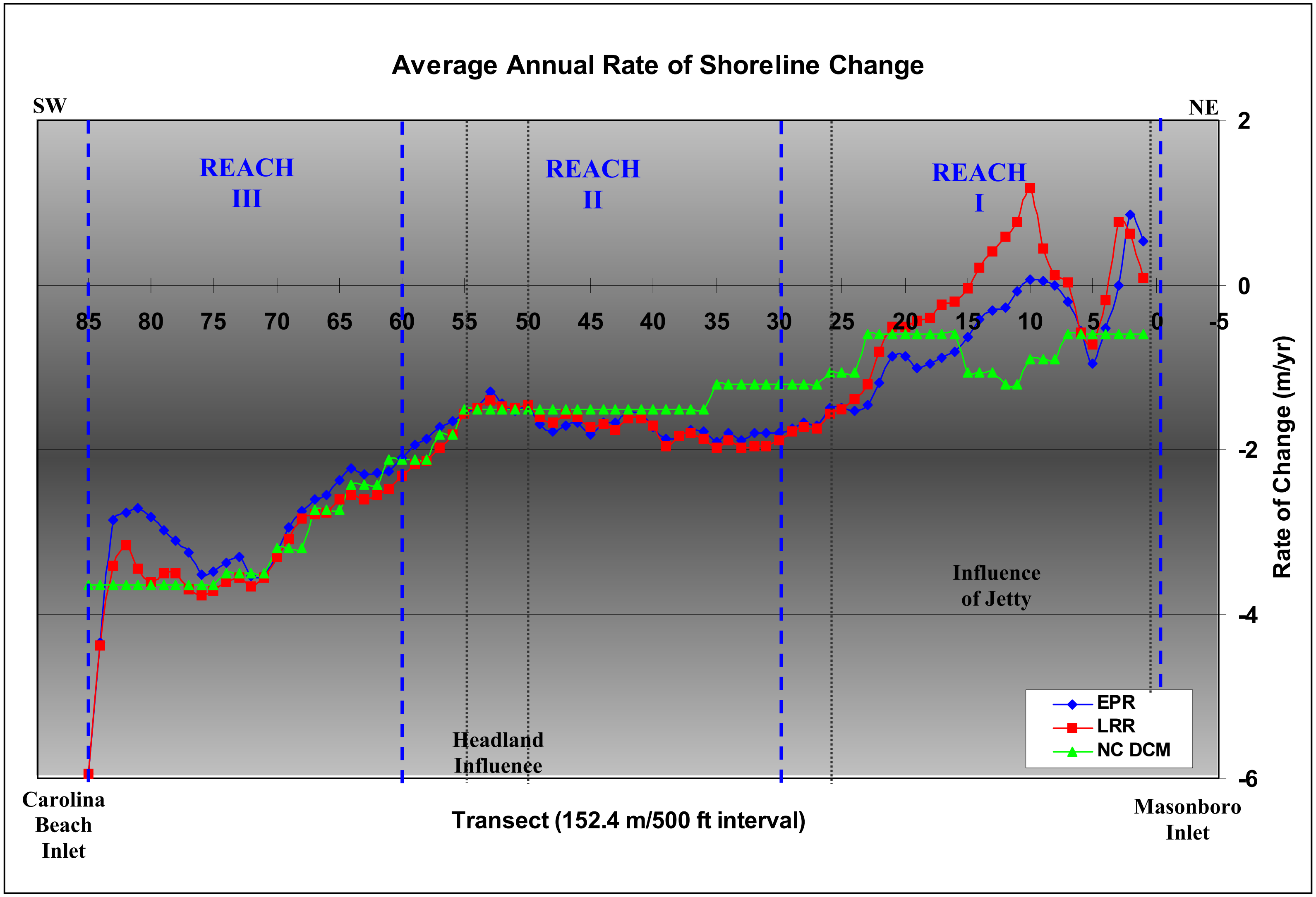

Figure 14. Comparisons of shoreline change rates by transect.

Period	Period Length (years)	Major Storm Events	Anthropogenic Impacts
March 22, 1938 - November 9, 1954	16.6	Hurricane Hazel (category 4) made landfall along NC/SC border on October 15, 1954.	Carolina Beach Inlet artifically opened in 1952.
November 9, 1954 - May 4, 1962	7.5	The Ash Wednesday storm stalls offshore between March 6-8, 1962.	
May 4, 1962 - November 1, 1975	13.5		The northern weir jetty stabilizing Masonboro Inlet was completed in 1966.
November 1, 1975 - October 16, 1982	7.0		The southern jetty stabilizing Masonboro Inlet was completed in 1981. In April and May of 1981, ~306,000 m^3 of sand was removed from Carolina Beach Inlet and placed on Carolina Beach.
October 16, 1982 - November 29, 1993	11.1	Halloween Storm of October, 1991 pounded the NC coast for 5 days.	Between April and August of 1986, ~841,000 m^3 of sand was placed along the north end of the island. A total of over 2.1 million m^3 of sand was removed from Carolina Beach Inlet in 1985, 1988, and 1991.
November 29, 1993 - September 23, 1996	2.8	Hurricane Bertha (category 2) made landfall on July 22, 1996. Hurricane Fran (category 3) made landfall on September 5, 1996.	~275,000 m^3 of sand was placed along the north end of the island between March and June of 1994. Between February and May of 1995, ~840,000 m^3 of sand was removed from Carolina Beach Inlet.
September 23, 1996 - May 16, 2002	5.7	Hurricane Bonnie (category 3) made landfall on August 26, 1998. Hurricane Floyd (category 2) made landfall on September 16, 1999.	Over 420,000 m^3 of sand was placed along the north end of the island during March and April of 1998. Almost 1.0 million m^3 of sand was removed from Carolina Beach Inlet in 1998.

Table 2. Long-term monitoring periods and significant milestone events that occurred during each period.

The period between 1938 and 1954 includes the artificial opening of Carolina Beach Inlet in 1952 along the southern portion of the island and the impact of Hurricane Hazel in 1954. Hurricane Hazel produced significant shoreline erosion along Reach I and actually widened Masonboro Inlet by almost 1 km (Figure 15). The average erosion along this reach was 66 m (218 ft) with a maximum amount of erosion of 153.8 m (504.7 ft) occurring near Masonboro Inlet at transect 10 (Figure 16A). Erosion along the central reach (Reach II) amounted to an average of 25 m (82 ft) during the 16-year period, while erosion along the shoreline perched on top of the headland, located at the southern end of Reach II, amounted to 13.8 m (45.1 ft). Prior to the opening of Carolina Beach Inlet, Reach III was relatively stable (USACE, 2000), and this stability is reflected by the fact that the average erosion of this section of shoreline amounted to only 7 m (22.9 ft) between 1938 and 1954 (Figure 17).

The second time period spans between 1954 and 1962 and includes the impact of the Ash Wednesday Storm in 1962 (Figure 16B). Despite the impact of this major extra-tropical storm, the northern two-thirds of the island built seaward during the 7.5-years following Hurricane Hazel (1954). During this time, Reach I prograded an average of 21.6 m (71.0 ft) while Reach II accreted nearly 24.5 m (80.5 ft). Shoreline change in the vicinity of the small headland was similar to the remainder of Reach II with an average progradation of 23.7 m (77.7 ft). In contrast, shoreline erosion along Reach III significantly increased to -17.1 m (-56.2 ft) or -2.3m/yr, which is over five times higher than the rate of the previous period that accounts for the impact of Hurricane Hazel (1954). The shoreline in the vicinity of transect 85, adjacent to Carolina Beach Inlet, had the highest amount of erosion during this period, which totaled -93.8 m (-307.8 ft).

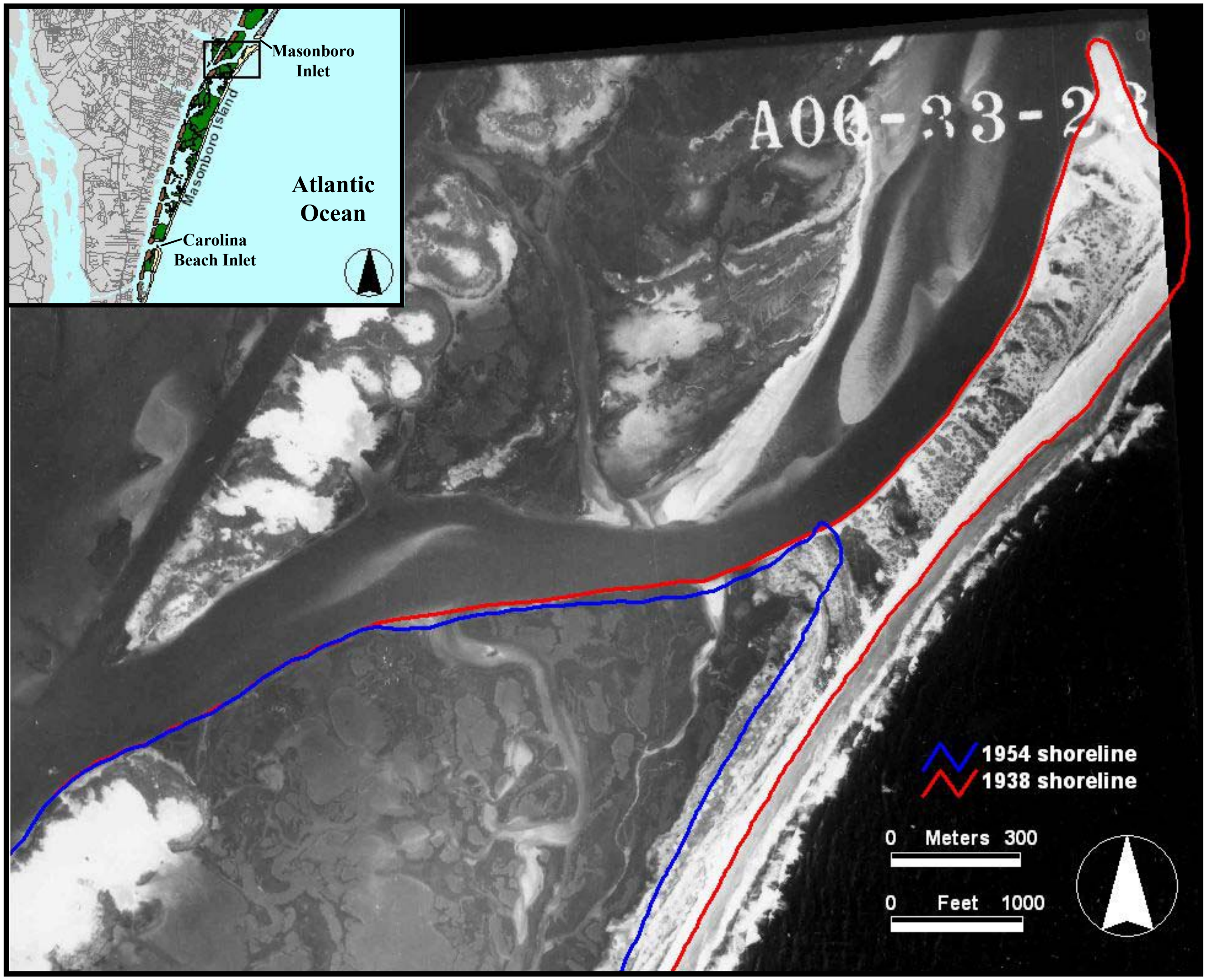

Figure 15. 1938 and 1954 shorelines adjacent to Masonboro Inlet illustrating changes resulting from the impact of Hurricane Hazel in October, 1954. The storm widened the inlet in excess of 1,100 m.

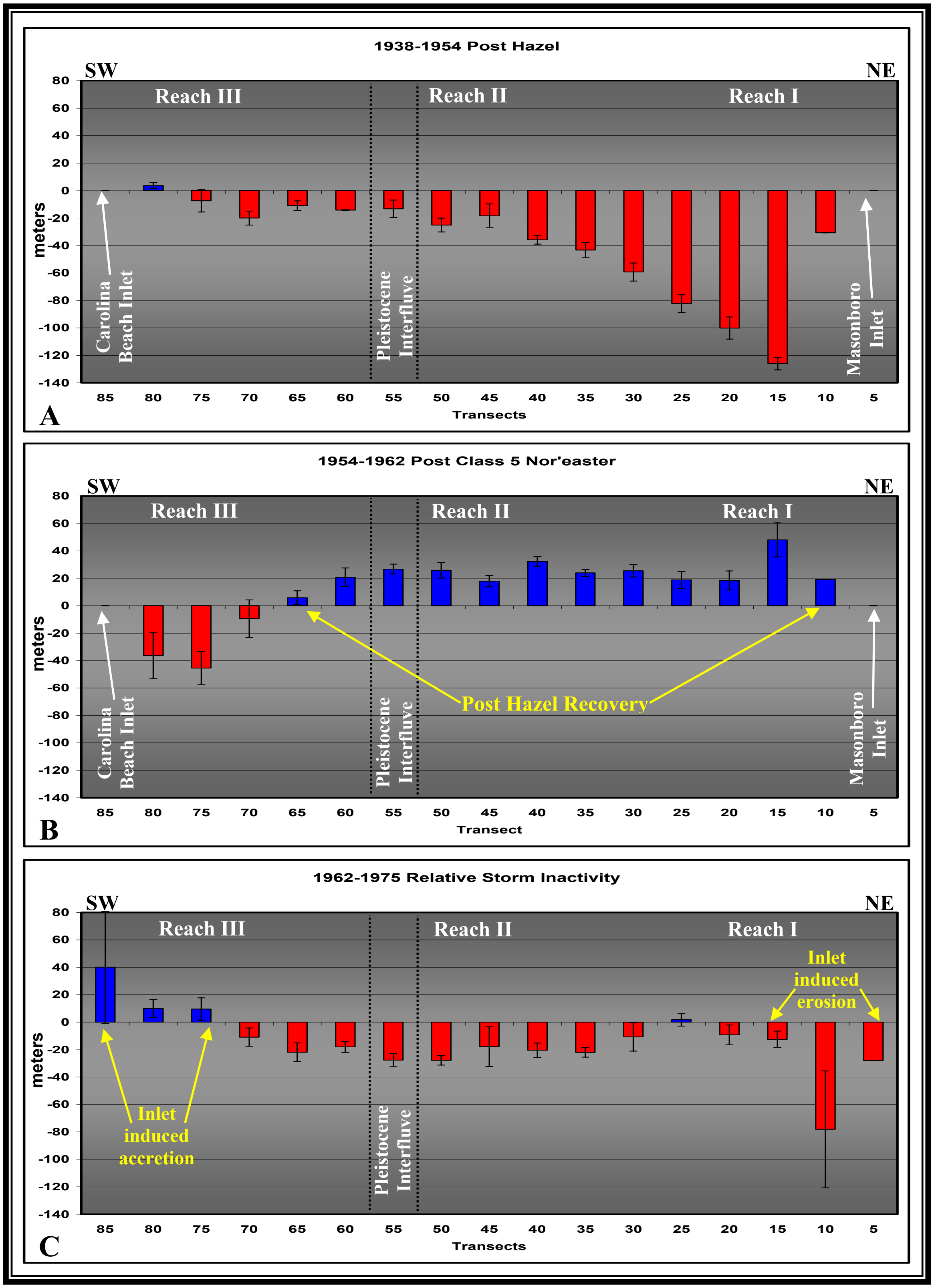

Figure 16: Average shoreline change by period. (A) 1938 – 1954 (B) 1954 – 1962 (C) 1962 – 1975 Error bars indicate standard deviation among individual transects.

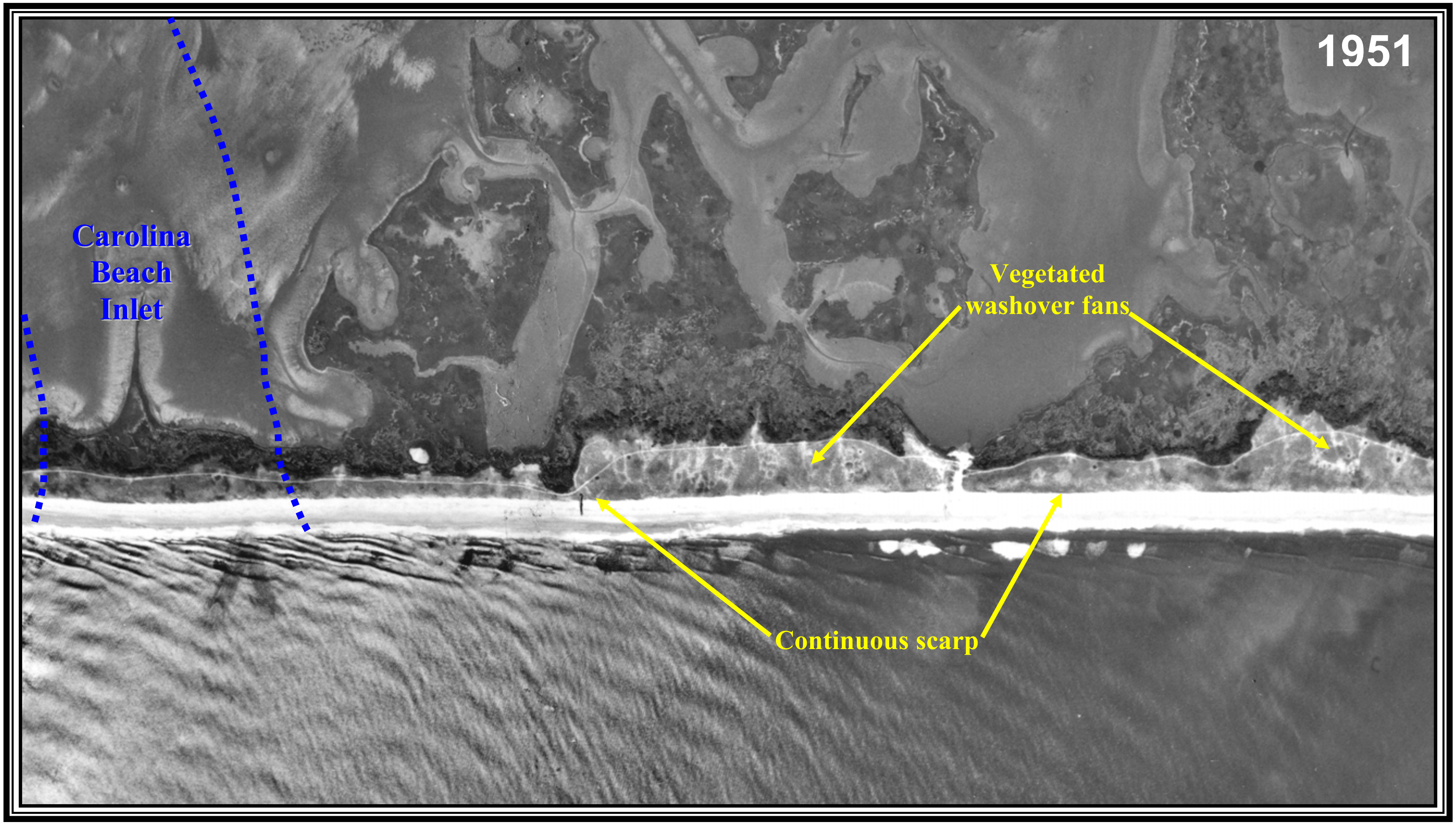

Figure 17. Photograph (3/31/1951) of the south end of Masonboro Island prior to the opening of Carolina Beach Inlet in 1952 (See Figures 2 and 3). Pre-inlet shoreline condition was characterized by a continuously scarped but well-vegetated dune line. The opening of the inlet destabilized the shoreline and extensive erosion followed. This photograph depicts the southern most portion of Reach III.

The period between 1962 and 1975 is marked by an absence of any major storm influences, and it includes the completion of the northern jetty along Masonboro Inlet in 1966 (Figure 16C). During the aforementioned interval, Reach I eroded an average of 22.8 m (74.9 ft), and a similar amount of erosion occurred along Reach II (22.3 m/73.2 ft). However, the average erosion for Reach I would have been much higher, but for a small section of shoreline between transects 20 and 24 that built seaward ~3.4 m (11 ft). Once again, the boundary between Reach II and Reach III, which is marked by a small headland, had erosion similar to that of Reach II. Erosion along this small reach of shoreline during this period was 22.8 m (74.9 ft). The southernmost shoreline segment along the southern section of the island near Carolina Beach Inlet (Reach III) managed to build seaward an average of 5.4 m (17.6 ft).

There were minimal storm impacts between 1975 and 1982 but extensive inlet modification did occur, during which time there was an average net change of -14.4 m (-47.4 ft) along Reach I (Figure 18A). This net value is misleading, however, because much of the northern half of Reach I prograded significantly as a result of the recently completed jetty (Figure 19). The northern portion of Reach I (transects 1 – 11) prograded an average of 22.9 m (75.2 ft) while the southern section of Reach I (transects 12 – 30) eroded an average of 31.2 m (102.5 ft). The central reach (Reach II) continued to erode and retreated an average distance of 17.3 m (56.8 ft). The shoreline along the south end of Reach II in the vicinity of the Pleistocene headland prograded ~ 0.9 m (2.92 ft), but it appeared that the headland influence was positioned slightly farther to the north near transects 48 and 49. The southern section of the island (Reach III) experienced the

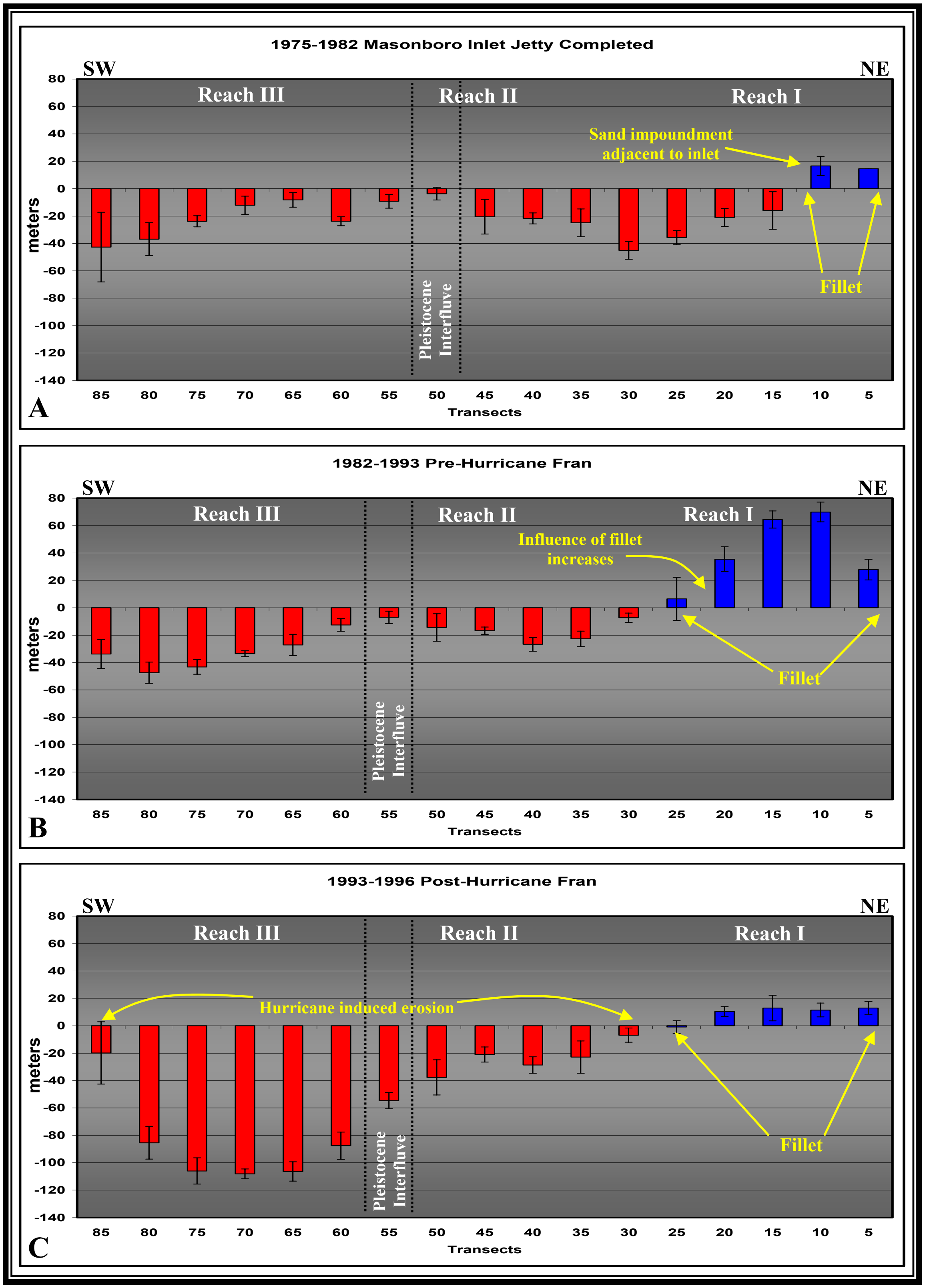

Figure 18: Average shoreline change by period. (A) 1975 – 1982 (B) 1982 – 1993 (C) 1993 – 1996 Error bars indicate standard deviation among individual transects.

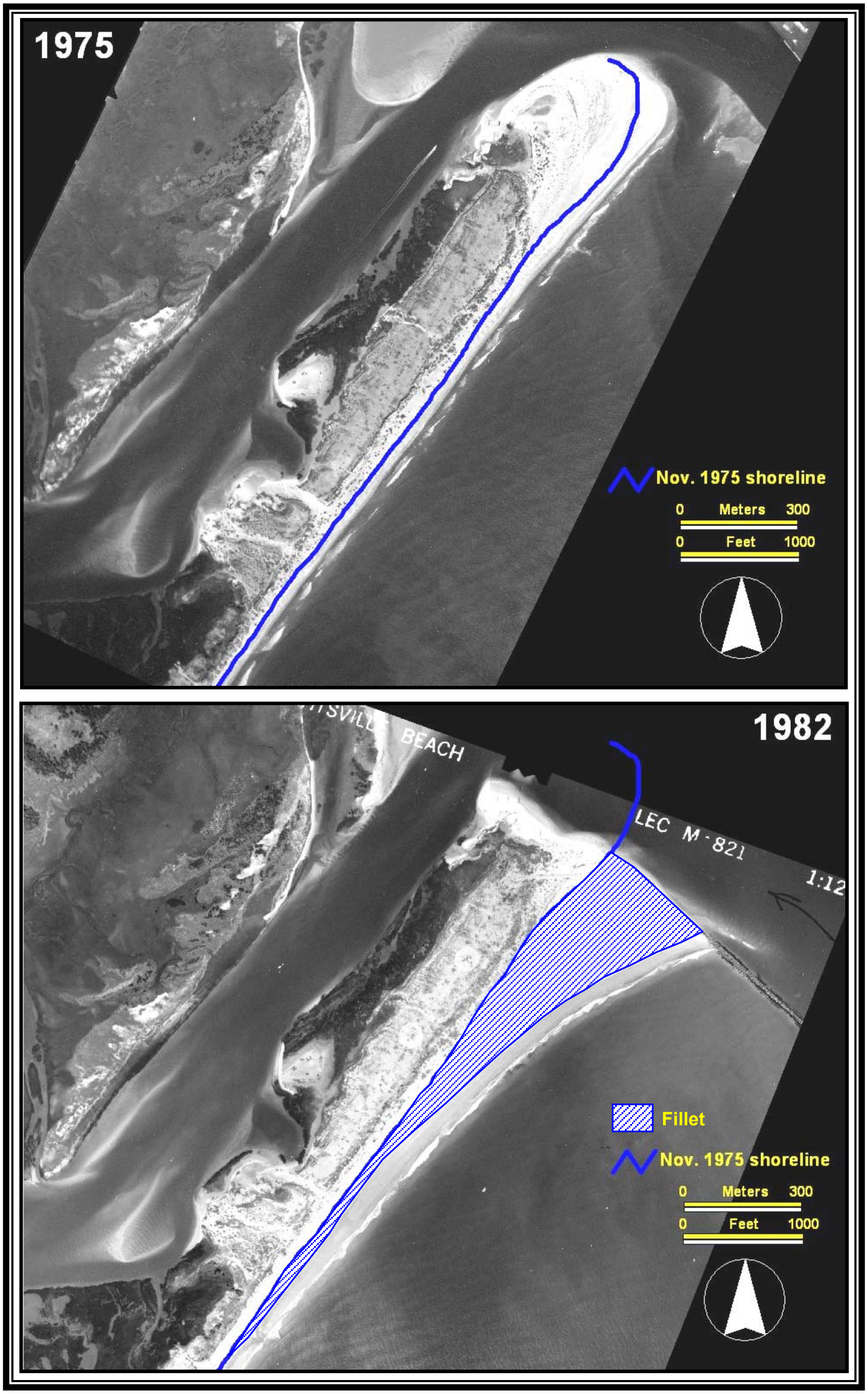

Figure 19. Aerial photographs (1975; 1982) depicting the rapid development of a fillet following the completion of the south rock jetty in 1981.

highest shoreline average retreat of -24.8 m (-81.2 ft). The shoreline along transects 82 – 83 adjacent to Carolina Beach Inlet eroded in excess of 76 m (250 ft).

The period between 1982 and 1993 was characterized by dramatic shoreline progradation within the fillet adjacent to Masonboro Inlet while significant shoreline erosion occurred to the south (Figure 18B). Reach I built seaward an average of 32.8 m (107.5 ft) while the central section (Reach II) continued to erode. The shoreline along Reach II eroded an average of -16.7 m (-54.7 ft) with erosion exceeding 30 m (98.4 ft) along the shoreline between transects 36 and 39. The behavior of the shoreline perched over the headland was similar to previous intervals and remained relatively stable (+1 m/+3.3 ft); however, the greatest influence of this headland appeared to shift farther to the south between transects 50 and 51. The highest amount of erosion occurred within Reach III and averaged -37.0 m (-121.5 ft) during this period.

An increase in hurricane activity occurred during the period from 1993 to 1996 and is marked by the landfall of Hurricanes Bertha (July 22, 1996) and Fran (September 5, 1996). During this interval, shoreline progradation along the northern reach (Reach I) was minimal and amounted to 6.6 m (21.8 ft), but the progradation was confined to the northern most sections of Reach I (transects 1 – 20). The remaining two-thirds of the island experienced dramatic shoreline erosion during this four-year period (Figure 18C). The shoreline within Reach II eroded an average of 42.1 m (138.1 ft) while the shoreline loss within Reach III averaged 85.1 m (279.3 ft). The shoreline in the vicinity of transect 68, within Reach III, had the greatest shoreline erosion amounting to -115.8 m (-372.6 ft). The amount of erosion steadily increased from Reach II to Reach III with no noticeable variation in shoreline change near the headland (transects 50 – 55).

Shoreline change between the period of 1996 to 2002 was influenced by the impacts of Hurricane Bonnie on September 26, 1998 and Hurricane Floyd on September 16, 1999 (Figure 20). During this time interval, Reach I and III remained relatively stable (-0.3 m/-1.0 ft and +0.8 m /+2.8 ft, respectively), while the central section of the island (Reach II) continued to retreat an average of 11.3 m (37.1 ft). Despite the stability of Reach I and III, however, there was significant variability in shoreline change within these reaches. The shoreline along Reach I experienced differential shoreline change with erosion concentrated between transects 1 – 9 (-11.7 m/-38.3 ft) and progradation confined to the south end of Reach I from transects 10 - 30 (4.6 m/15 ft). Likewise, Reach III could be divided into two sub-reaches with progradation in the vicinity of transects 61 – 69 amounting to 19.1 m (62.8 ft) and erosion near Carolina Beach Inlet (transects 70 – 85) amounting to10.8 m (35.4 ft).

Short-term Change

A GPS based survey of a 2,500 m section of shoreline centered over the Pleistocene headland was conducted over a 1.3 year period between July 2003 and November 2004. Although storm impact was relatively minor, this period does include the passage of Hurricanes Isabel (September 18, 2003) and Charlie (August 14, 2004) as well as several unclassified nor'easters. Shoreline change was measured at the wet-dry line along 14 transects in the vicinity of the shoreline perched over the Pleistocene headland, and each of these transects were grouped into three different zones based on their erosional characteristics. Note that in contrast to the transects used for measuring long-term change, the 14 transects and three zones in this section increase in number from south to north (Figure 10). Zone 1 (transects 1-5), located to the south of the small headland, had

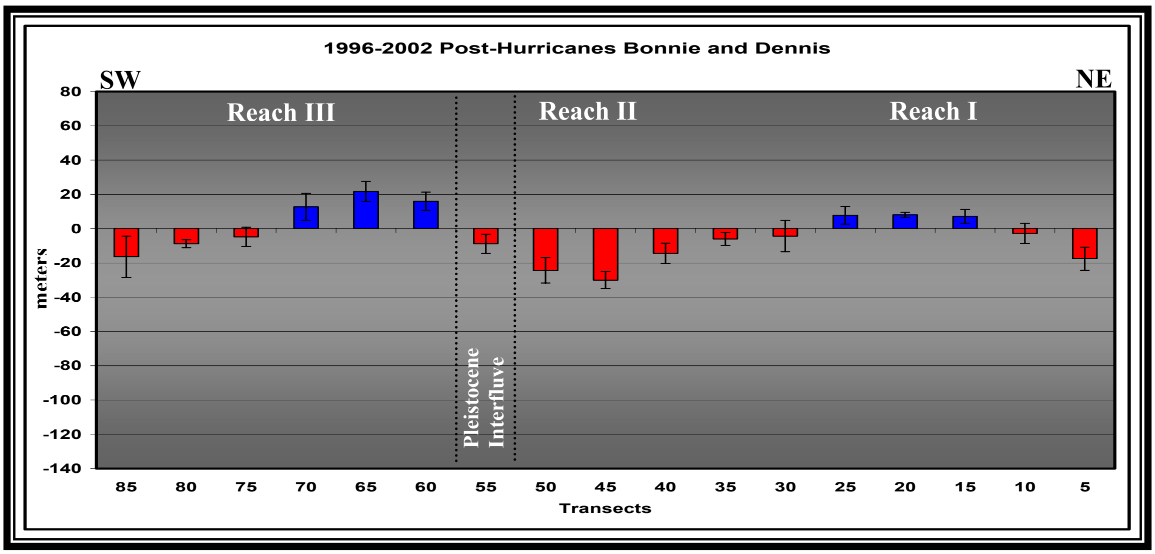

Figure 20: Average shoreline change for the period of 1996 – 2002. Error bars indicate standard deviation among individual transects.

an average net shoreline change of -30.7 m (±7 m) during the 1.3 year study period (Figure 21A). The central zone (Zone 2), which includes transects 6 and 7, was characterized by the least amount of shoreline retreat with recorded erosion of –16.9 m (±1 m). North of the headland, the shoreline within Zone 3 eroded 28.4 m (±6 m). The maximum amount of erosion recorded in all three reaches was in excess of 35 m (114.8 ft) and occurred at along transects 1, 2, and 11.

Shoreline change during the 16-month study period was divided into six different time periods based on the dates that the island was surveyed. The time interval between July, 2003 and September of 2003 includes the passage of Hurricane Isabel, and during this time the shoreline in all three zones translated landward. Zone 1 on the south flank of the headland eroded 13 m (42.7 ft) while Zone 3 to the north eroded 12.7 m (41.7 ft). In contrast, the shoreline within the central zone retreated only 6.2 m (20.2 ft), half the amount of the adjacent zones. The six-month period between September 2003 and March 2004 was characterized by erosion along Zone 1 (-4.4 m/-14.5 ft) and Zone 3 (-2.6 m/-8.5 ft). In contrast, Zone 2 built slightly seaward (1.2 m/4.0 ft) during the same period. During April 2004, Zone 1 remained relatively stable with a loss of 0.6 m (1.9 ft); however, Zones 2 and 3 to the north had an average erosion of 5.8 m (19.1 ft) and 4.1 m (13.3 ft). During May 2004, shoreline retreat was confined to Zone 1, where a change of -4.1 m (-13.5 ft) was recorded. Zone 2 had no recorded change while Zone 3 prograded an average of 2.4 m (7.8 ft). Hurricane Charlie (2004) made landfall during the period between June 1, 2004 and August 17, 2004, but any adverse impacts along the reaches were not readily apparent. During the aforementioned time interval, Zone 1 prograded 1.7 m (5.6 ft) while Zone 3 to the north prograded 5.7 m (18.7 ft). The central zone again

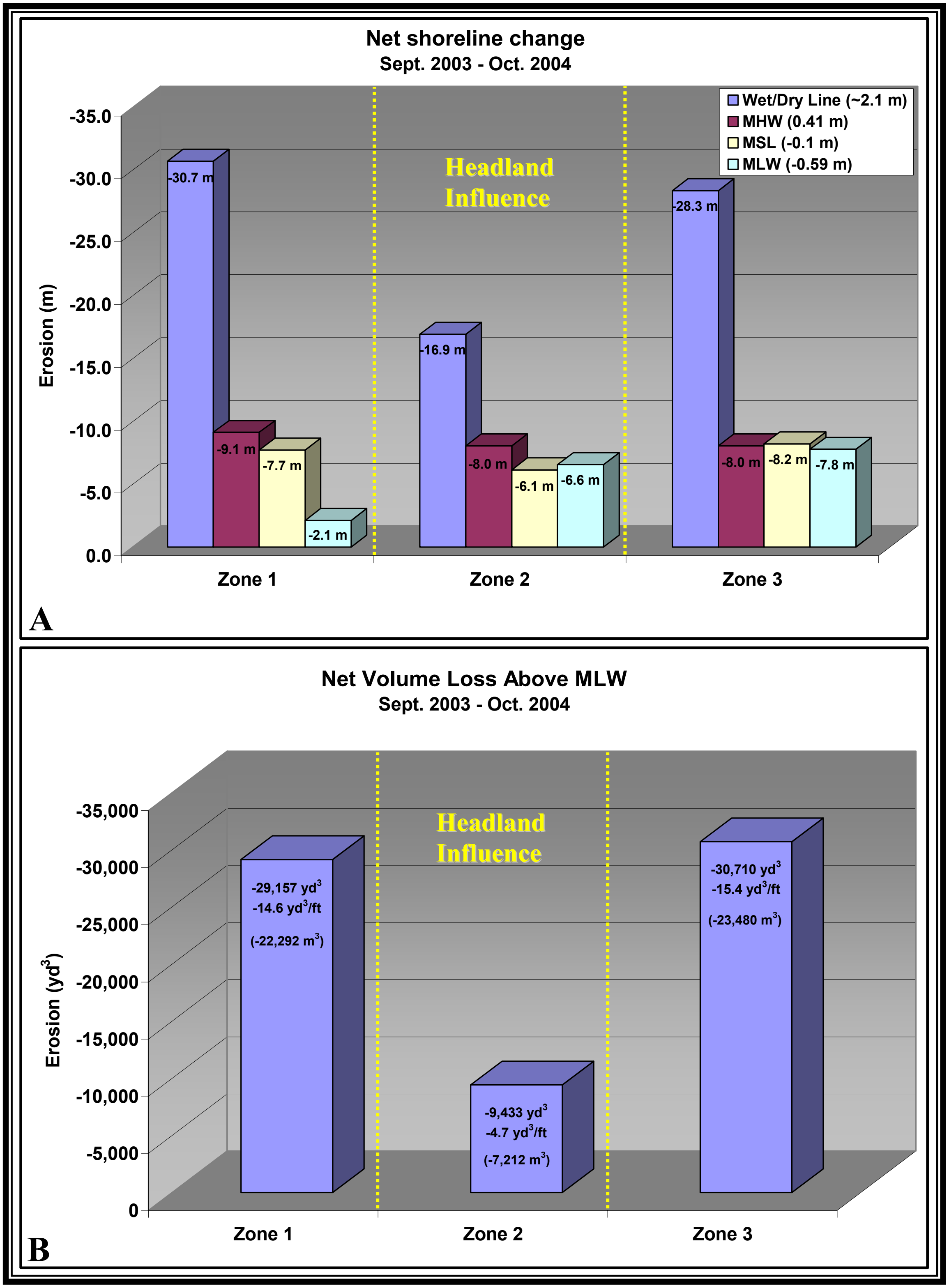

Figure 21. Changes along a 1,700 m section of shoreline in the vicinity of the Pleistocene headland that occurred between September, 2003 and October, 2004. (A) Net shoreline change measured along the wet/dry line (~2.1 m), MHW (0.41 m), MSL (-0.1 m), and MLW (-0.59 m). (B) Net volume loss of sediment and the corresponding erosion rate per linear foot.

remained relatively stable with only 0.8 m (2.7 ft) of erosion. The final survey period between August 17 and November 15, 2004 was marked by an increase in shoreline retreat along all three zones with Zone 3 having the greatest amount of erosion 15.3 m (50.1 ft). Zone 1 had the second highest amount of change that amounted to -12.1 m (-39.7 ft), while only -5.3 m (-17.5 ft) was recorded within Zone 2 in the vicinity of the headland.

Volumetric Changes and Profile Changes

Fourteen shore-normal profiles were surveyed along a 1,706 m (5,600 ft) stretch of shoreline in order to characterize changes in the barrier's profile and the volume of sediment lost in the vicinity of a small Pleistocene headland (Figure 10). During the survey period (1.3-year), this segment of shoreline lost 53,000 m^3 of material above MLW, which translates to an average loss of 24,000 m^3/km/yr. Calculations were also made for the volume of sediment lost above MSL and MHW, which amounted to 20,700 m^3/km/yr and 17,600 m^3/km/yr, respectively. The average contour change at MLW was -5.6 m. Likewise, average contour change recorded along MSL was 7.2 m (-23.5 ft) and 8.2 m (-26.8 ft) at MHW. Shoreline changes along this area were not uniform but occurred at varying rates within three separate zones.

Zone 1 includes transects 1 – 5 and is the 610 m (2,000 ft) shoreline segment located immediately south of the headland. The net volume of sand lost along the beachface within this zone amounted to 22,292 m^3, which equates to an average volumetric change of -36.8 m^3/m measured above MLW. Average contour changes at MLW, MSL, and

MHW along this zone were -2.1, -7.7, and -9.1 meters, respectively (Figure 21A-B). Similarly, Zone 3 (transects 8 – 14), north of the headland, experienced a net erosion above MLW of 23,480 m^3 or 38.9 m^3/m. Average contour changes in this area were -7.8 m at MLW, -8.2 m at MSL, and -8.0 m at MHW. In contrast, Zone 2 (transects 6 – 7), which includes the shoreline segment perched over the Pleistocene headland, had significantly less erosion during the same period. Erosion along this reach amounted to 11.9 m^3/m and a volume loss of 7,212 m^3 above MLW. Contour changes were slightly less than surrounding reaches with an average shoreline retreat at MLW, MSL, and MHW of -6.6 m, -6.1 m, and -8 m, respectively. The amount of erosion calculated from the wet-dry line was significantly higher within all three zones when compared to the amount of erosion recorded at MHW, MSL, and MLW (Figure 21A). Furthermore, shoreline changes varied both temporally and spatially within each zone.

Backbarrier Stratigraphy

A suite of 17 vibracores was retrieved from a 1 km^2 section of the estuary positioned over a Pleistocene interfluve in order to ascertain the nature and distribution of the sediments that comprise the interfluve (Figure 11). The cores, which ranged in length from 96 cm to 503 cm, were used primarily to determine the depth of the Holocene fill and secondarily to ascertain the characteristics of the Holocene and Pleistocene sediments. In addition, two shore normal core profiles (Figures 22-23), and two shore parallel core profiles (Figures 24-25) depict the elevations of different stratigraphic units below mean sea level. Detailed core descriptions are located in Appendix C.

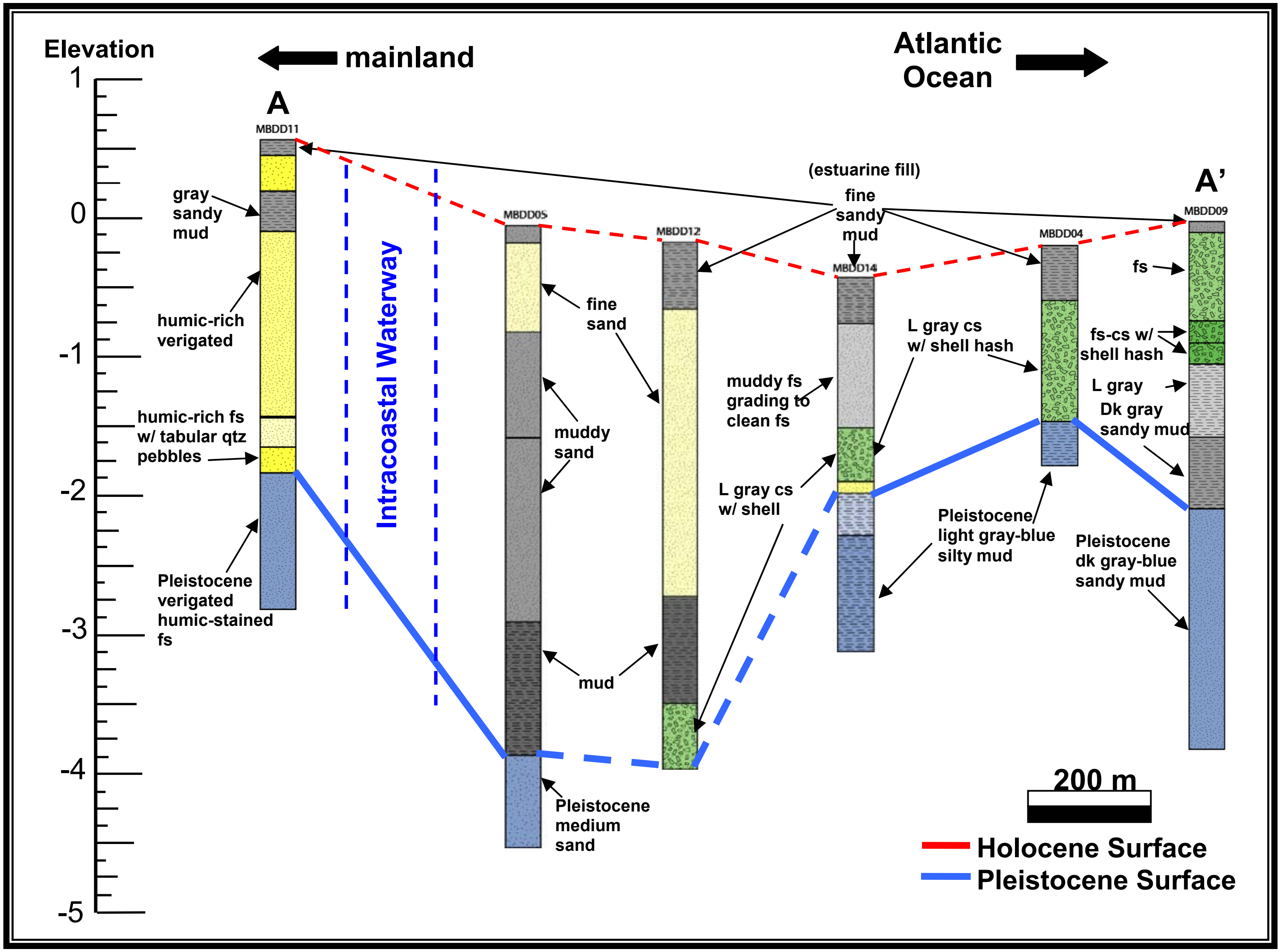

Figure 22. Shore-normal stratigraphic profile of Transect A – A'.

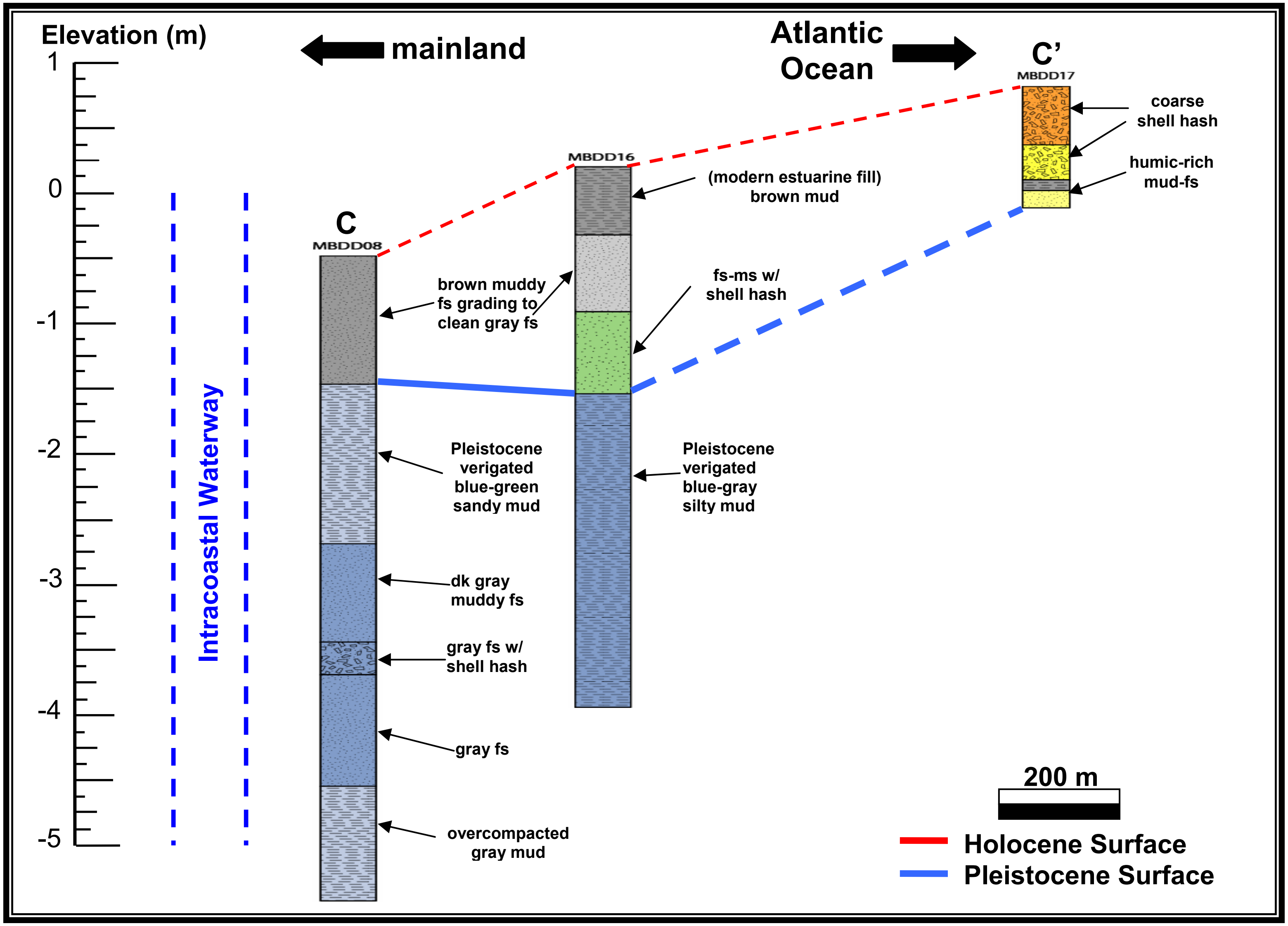

Figure 23. Shore-normal stratigraphic profile of Transect C – C'.

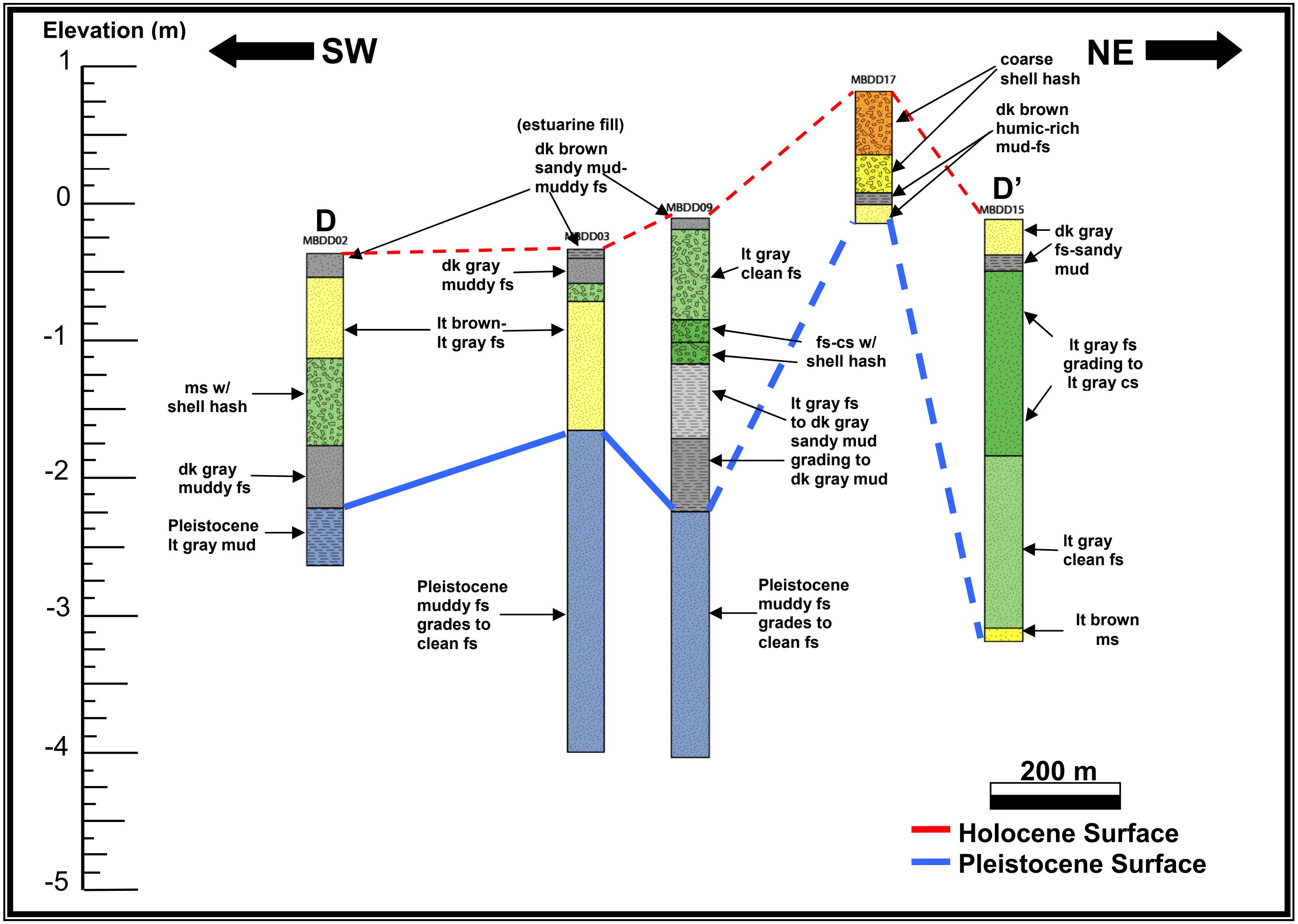

Figure 24. Shore-parallel stratigraphic profile of Transect D – D'.

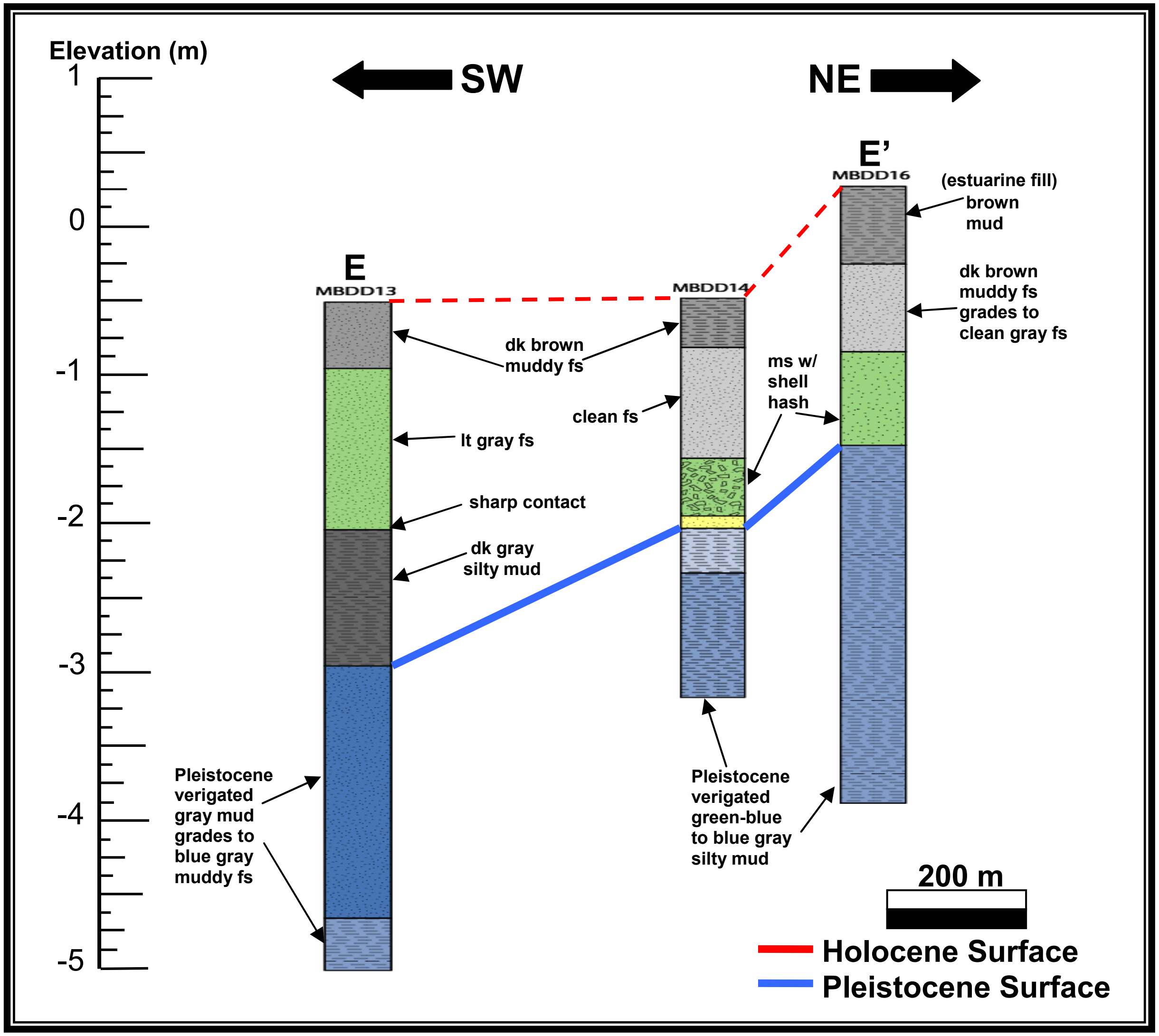

Figure 25. Shore-parallel stratigraphic profile of Transect E – E'

The Holocene fill was relatively shallow and ranged in depth from 1.5 m over paleo-interfluves to depths greater than 4 m over sections of infilled valleys. The dominant Holocene sediments listed in order of abundance were muddy sand to sandy mud, clean fine grained quartz sand, medium to coarse grained quartz sand, very fine to fine grained quartz sand, and mud. Muddy sand to sandy mud comprised the majority of the cored Holocene sediment (39.9%) and primarily represents the modern estuarine fill. These sediments were generally dark brown in color and contained abundant marsh roots (*Spartina* sp.) and occasional mud snails (*Nassarius* sp.). Approximately 18.5% of the sediment was clean fine quartz sand that was typically light gray in color and contained no silt or mud and only minor amounts of shell material. Medium to coarse grained sediment accounted for 17% of the cored material, and this sediment frequently contained an abundance of sand to gravel size shell material. The very fine to fine grained quartz sands comprised 14.3% of the sediment and ranged from gray to dark brown in color depending on the amount of mud present. Dark gray to dark brown mud accounted for 10.2% of the cored material.

Pleistocene sediments were generally recognized as thick overcompacted (de-watered) mud or well-sorted fine grained quartz sands beneath the modern estuarine fill. The underlying Pleistocene sediments were divided into four broad categories based on grain size. The dominant sediment type was muddy quartz sand to sandy mud, which comprised 41% of the retrieved Pleistocene sediments. This facies typically ranged from dark gray to bluish gray in color and was often variegated. Very fine to fine quartz sands that were frequently stained an orange to yellowish brown were also very common (40.3%). A thick over-compacted mud was also common (13.4%) in the Pleistocene sequence. The dense mud varied in color from grayish blue to olive green to dark gray. The least common sediment was medium to coarse grained quartz sand, which composed only 5.3 % of the sequence.

Petrology

Eight rock and sediment samples were obtained from the intertidal area and washover fan in the vicinity of the headland, along Snow's Cut, and from Friendly Lane (Figure 4). Thin-section analysis of rock samples from the island and Snow's Cut provided information about the lithology of the coquina found at Snow's Cut and in the vicinity of the headland. In addition, the nature and distribution of the petrographic data were used to establish a correlation between local outcrops of semi-indurated, humic-rich sands found along Snow's Cut and Friendly Lane, and to provide information about the source of the sediments found along the shoreline. The coquina and humic-rich sands along Snow's Cut are the same exposures that were described by DOCKAL (1996).

One coquina sample was taken from Snow's Cut (Sample # SC-Coq) and three more samples (Sample #s MB-FG, MB-MG, MB-CG) were taken from the intertidal-zone near the Pleistocene headland (Figure 4). Modal analysis indicates that the coquina is categorized as a sandy biosparite based on the FOLK (1980) carbonate classification system. The siliciclastic fraction of the clasts in the rock samples ranged from 49 – 57% monocrystalline quartz and 1 – 11% polycrystalline quartz with an average phi-size of 0 to 1. The grains were moderately sorted and ranged from sub-angular to well-rounded. Well-rounded molluscan shell fragments were the second most abundant constituent of the coquina clasts ranging from 36 – 47% with an average phi-size of -1. Alteration of the bioclasts ranged from minor micritization of the outer margins to complete re-crystallization. In addition to the quartz and shell fragments, 3 – 8% of the clast material was feldspar, all of which was cemented predominately with spar calcite (Figure 26).

Grains composing the two sediment samples (MB-Berm; MB-Fan) retrieved near the headland from the berm and washover fan were very similar in composition and phi-size when compared to the coquina samples (Figure 26). The siliciclastic sand fraction was sub-angular to well-rounded and ranged from 53 – 55% monocrystalline quartz. The phi-size of the quartz fraction was 0 to 1, with only minor amounts of polycrystalline quartz. Some of the polycrystalline quartz grains showed signs of metamorphic straining. An additional 30 – 39% of the sediment was well-rounded carbonate material between -1 and -2 phi. The remaining fraction was composed of feldspar (1 – 8%) and rock fragments (3 – 5%). The majority of the lithic fragments in the sediment were rounded pieces of coquina that were very similar in grain size, composition and roundness to the coquina found along the intertidal zone (Figure 27) and at Snow's Cut (Figure 5).

The remaining two samples of humate sand were taken from Snow's Cut (SC-SS) and at the terminus of Friendly Lane (FL-SS) several kilometers to the northeast (Figure 4). These samples were similar to the semi-indurated sand exposed along shoreline above the headland following Hurricane Fran in 1996 (CLEARY *et al*., 1999). Both samples were dominated by angular to rounded monocrystalline quartz (83 – 87%) with an average phi-size of 2 (Figure 26). The remaining mineral fractions of the samples were feldspar (7 – 11%), polycrystalline quartz (3 – 5%), and lithic fragments (<1%). The samples did not contain any carbonates and were both heavily enriched with humate material.

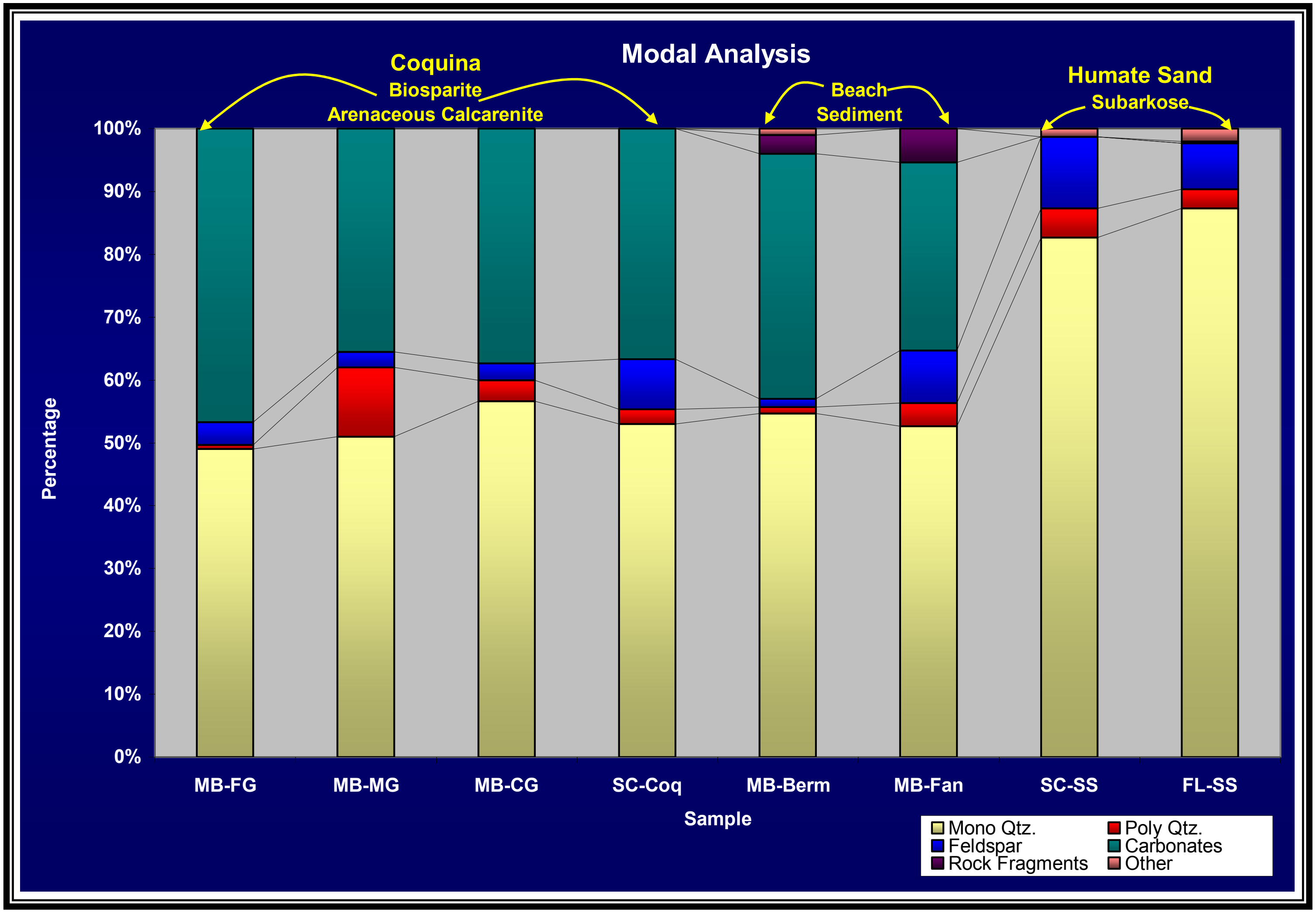

Figure 26. Composition of rock and sediment samples collected from Masonboro Island, Snow's Cut, and Friendly Lane. Note that the composition of the coquina is very similar to the samples collected from the berm and washover fan. All of the samples are similar when normalized for the presence of carbonates.

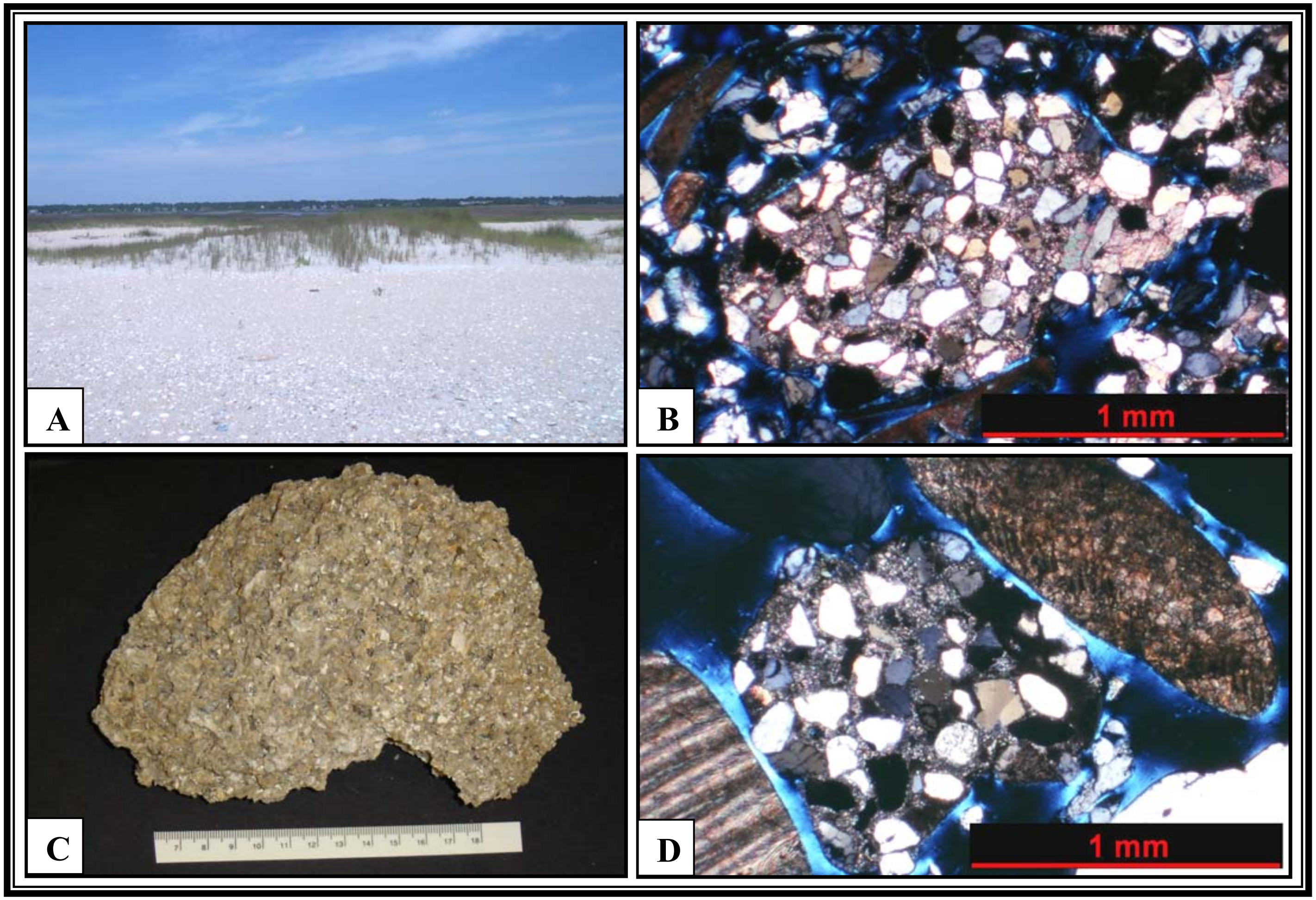

Figure 27. (A) West view of island in the vicinity of a Pleistocene headland. Note the flat barrier profile. Dune is <1 m in local relief. (B) Photomicrograph of coquina recovered from the intertidal zone near the headland. Quartz sand and shell fragments are cemented with spar calcite. (C) Photograph of coquina recovered from intertidal zone. (D) Representative photomicrograph of coquina clasts found in backshore sediments. Note the similarities between the rock and sediment samples.

DISCUSSION

Arguably one of the most important issues of studying barrier island evolution is to understand the processes of morphological change and the environmental factors that control these changes. Major storms frequently impact Southeastern North Carolina, and as a result, beach nourishment has become common practice for erosion mitigation. In addition, inlets are often modified with the intent of stabilizing the system, but the effectiveness of these practices is questionable at best. This study of Masonboro Island provides a unique opportunity to evaluate the impacts of storm events, inlet modification, and inherent geologic framework on barrier evolution in a sand-starved environment. Changes along the island can be analyzed without the complications associated with the extensive development that characterizes the majority of barrier islands on the East Coast. The principles of barrier evolution in response to these factors can then be locally applied to the surrounding developed islands. The discussion that follows is based primarily on the three main erosion reaches depicted in Figure 9 and the seven different time periods (1938 to 2002) outlined in Table 2

Long-term Change (Pre-1938 to 2002)

Masonboro Island experienced island wide shoreline erosion between 1938 and 2002, with the exception of a small (500 m) section restricted to the fillet zone at the north end of the island (Figure 12). The erosion, however, did not occur at a uniform rate through time nor did it occur at a uniform rate along the entire length of the island. Instead, there were typically distinct periods of shoreline change coinciding with significant storm events and inlet modifications followed by periods of limited erosion or in some cases minimal recovery along various sections of the shoreline. As a result of the highly variable nature of change during the period of 1938 to 2002, shoreline changes were divided into three different island reaches with characteristically different patterns (Figure 9). Furthermore, changes were divided into seven different time periods bracketed by major milestone events that occurred during the 64-year period (Table 2). Figure 28 illustrates the cumulative change along each reach in relation to storm impacts and inlet modifications.

Pre-1938 to 1954

Prior to 1938, Masonboro Island was relatively stable (USACE, 2000) and characterized by a continuously scarped but intact foredune and well vegetated washover fans (CLEARY and HOSIER, 1979). A report by the Army Corps of Engineers (USACE, 1982) stated that sediment accretion for the entire island between 1857 and 1933 averaged about 19,900 m^3/yr. In addition to a net surplus of sediment, a 1 km spit at the north end of the island that was imaged on the 1938 photography was not depicted on an 1858 historical map, indicating that the spit is a relatively recent feature compared to the rest of the island. The presence of recurved dunes on the spit (Figure 15) could indicate that the inlet was migrating to the northeast or that the spit had been repeatedly breached during storm events. Masonboro Island remained contiguous with Carolina Beach until 1952, but in that year Carolina Beach Inlet was opened by the Army Corps of Engineers to improve water quality in the sound and to provide local fishermen access to the Atlantic Ocean. The role Carolina Beach Inlet would play in the evolution of the

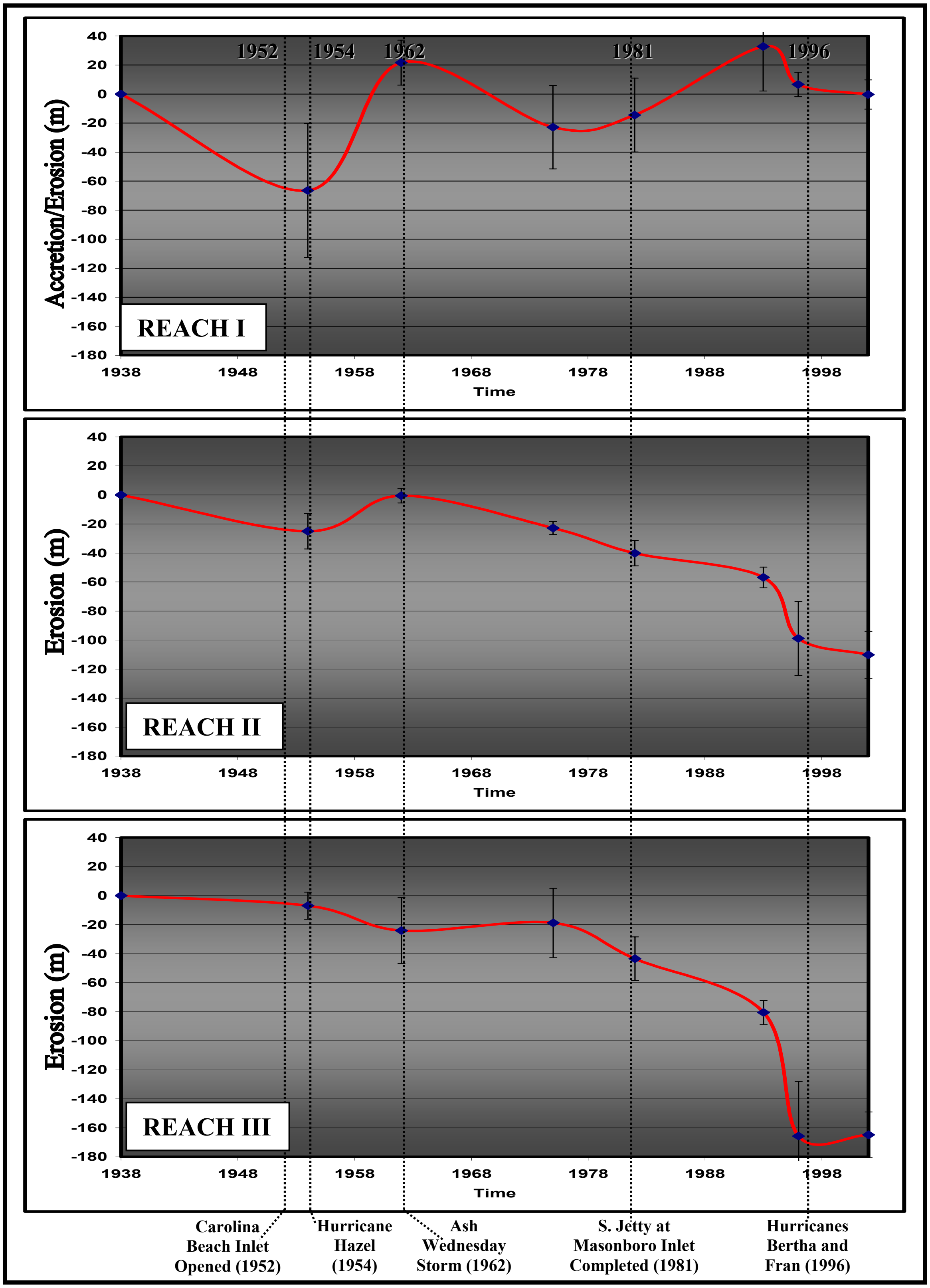

Figure 28. Cumulative shoreline change along each reach during the period of 1938 to 2002. Dates of major events are indicated by dashed timelines. Error bars indicate standard deviation of shoreline change during each time period.

south end of the island would not be readily apparent for several years, but the opening of the inlet would emerge as one of the most influential events affecting the southern two-thirds of the island.

Two years later in 1954, Hurricane Hazel made landfall to the south of Cape Fear and had a significant impact on the morphology of the island along all three reaches. Reach I at the north end of the island experienced the largest amount of change between 1938 and 1954. In addition to shoreline change, the dunes along the northern reach of the island were effectively leveled. As a result, a continuous washover terrace along this reach was produced during the storm with individual washover fans extended into the lagoon by as much as 140 m when calculated from the post-storm shoreline. Masonboro Inlet, which at this point remained unstabilized, was widened by almost 1 km when then northern most spit of the island was fully breached (Figure 15). The instability of the inlet during this time period allowed for significant shoreline change in response to storm impacts. The average shoreline erosion of Reach I was 66 m, and the highest amount of shoreline erosion (~130 m) occurred adjacent to Masonboro Inlet as a result of the expansion and re-orientation of the inlet during Hurricane Hazel (Figure 16A).

The remainder of the island experienced significantly less erosion following Hurricane Hazel when compared to changes recorded in Reach I (Figure 16A). Reach II had an average shoreline erosion of 25 m, which was ~62% less than the Reach I. Some washover fans extended into the estuary in excess of 110 m, but unlike the northern reach, the occurrence of washover fans in Reach II was much more sporadic. Reach III eroded the least amount between 1938 and 1954 despite the fact that Carolina Beach Inlet had been opened for two years. One would expect that the shoreline immediately adjacent to a newly opened inlet would have the greatest amounts of erosion as a result of changes in equilibrium, but the data show otherwise. It is possible that the recently opened inlet did not have a sufficient amount of time to sequester large volumes of sand. Subsequently, the average erosion of Reach III (7 m) was ~90% less than the amount recorded within Reach I (66 m). Furthermore, washover fans within Reach III were more sporadic and smaller (~50 m) than the other two reaches indicating that storms had less of an impact on the dune system. However, it is difficult to differentiate between the influences of the newly opened inlet (1952) and the influences of the Hurricane Hazel (1954) because data were not available from the period of time between the opening of the inlet and the landfall of the hurricane. It is likely that both the inlet and the storm played a role in the erosion that occurred along Reach III.

A small section of shoreline within Reach II that had overridden a Pleistocene headland eroded an average of 13.8 m between 1938 and 1954. This rate is similar to the average erosion rates recorded within Reach III (Figure 16A). The similar erosion rates indicate that erosion along the shoreline perched over the headland was controlled by the same processes that control erosion within Reach III. Similar rates of erosion may also suggest that the beach had not yet become perched on the headland in a way that would allow the headland to affect erosion. The influence of the headland became more apparent through time as the island continued to translate landward and the beach became increasingly perched over the submerged portion of the headland.

1954 to 1962

The erosional characteristics of the island between the period of 1954 and 1962 were remarkably different from those of the previous period. The northern two-thirds of the island were in a state of foredune recovery, with Reach I and II prograding an average of 21.6 m and 24.5 m (Figure 16B). In addition, the spit that was formerly located along the northern end of the island prior to Hurricane Hazel (1954) was artificially replaced by the Army Corps of Engineers in preparation for the construction of the north jetty at Masonboro Inlet (CLEARY, pers. comm., 2004). The reconstructed spit extended the length of the island by ~1,300 m. It is important to note that the reported amount of seaward buildup in these areas includes the impact of the Ash Wednesday winter storm in 1962. Had pre-storm data been available, the amount of progradation may have been significantly greater than the values reported after the storm.

Even though the shoreline with in Reaches I and II prograded between 1954 and 1962, it is likely that a low barrier profile and lack of significant dune coverage prior to the Ash Wednesday Storm made the northern reaches susceptible to oceanic overwash, though profile data to support this assumption were not available. Aerial photography indicates the storm extended the existing washover terrace within Reach I an additional 60 m into the estuary or a total of 180 m when measured from the post-storm shoreline. The storm also produced washover fans similar in magnitude along Reach II, but the fans were much more sporadic in nature.

Reach III previously (1938 to 1954) experienced minor erosion (~7 m), but during the period between 1954 and 1962, the amount of erosion more than doubled to an average of 17.1 m (Figure 16B). The greatest amount of erosion occurred adjacent to Carolina

Beach Inlet (~40 m), while the northern most extent of the reach built slightly seaward. During this same period, the southern tip of the island extended to the southwest by ~850 m. The increase in erosion and inlet migration suggest that the previously stable section of the barrier at the southern end of Reach III had become increasingly unstable following the opening of Carolina Beach Inlet.

Several factors contributed to these erosional trends. The southern portion of Reach III was destabilized following the opening of the inlet because the ebb channel acted as a sink for littoral sediment. It was estimated that 3,181,000 m^3 of sediment was eventually impounded in the newly opened inlet with about 2,485,000 m^3 of that sediment comprising the ebb tidal delta (USACE, 2000). It was also reported that between 1956 and 1966 there was a sediment deficit of approximately 118,000 m^3/yr directly due to Carolina Beach Inlet (USACE, 2000). Although the Corps of Engineers used slightly different time periods than the periods in this study, the estimated sediment deficit should be a reasonable estimate for the period between 1954 and 1962. The initial influence of the inlet was limited to the southern most section of the island, but it would gradually destabilize longer sections of the southern segment of the island as the island evolved.

Along with the entrainment of sand within the ebb tidal delta, the southern end of the island was extended when Carolina Beach Inlet began to migrate soon after it was opened. The inlet migrated to the southwest approximately 850 m before it stabilized. In addition, the Ash Wednesday Storm (1962) stalled offshore and affected the coast for three days, lowering the barrier profile and making the island more susceptible to overwash. In response to this storm, a massive washover terrace developed along the southern portions of Reach III extending over 160 m into the estuary from the post-storm shoreline. These data suggest that geomorphologic changes along Reach III between 1954 and 1962 were the result of the combined effect of sand impoundment in the inlet, inlet migration, and the Ash Wednesday Storm.

1962 to 1975

In 1966, the Army Corps of Engineers completed the construction of a weir jetty along the northern shoulder of Masonboro Inlet. The purpose of the weir was to allow littoral sand from the north to bypass the jetty and collect in a depositional basin. This sediment could then be dredged and bypassed to adjacent Wrightsville Beach and Masonboro Island on an alternating year basis (USACE, 2000). However, sand still migrated north into Masonboro Inlet due to the littoral transport by southeasterly waves during the summer months and due to sand pushed north by wave refraction around the ebb tidal delta. As a result, the spit at the north end of Masonboro Island built to the northeast, and the ebb channel was re-oriented to a position immediately adjacent to the jetty (USACE, 2000). The channel shift caused the northern section of Reach I to erode as a consequence of the planform adjustment. The net result of the planform adjustment was an average erosion of 22 m along Reach I during the period between 1962 to 1975 with the highest amounts of erosion (>80 m) occurring within the northern 30% of Reach I adjacent to Masonboro Inlet (Figure 16C).

Carolina Beach Inlet had a very different impact on the southern section of the island during the same period of time. In 1967, a sediment trap with a capacity of 76,000 m^3 was dredged within the inlet throat to serve as a borrow source for Carolina Beach. The sediment trap was again dredged in 1971, and approximately 216,000 m^3 of sediment were placed along Carolina Beach. During this same period (1962 to 1975) the inlet migrated to the northeast nearly 200 m, and the main throat was realigned adjacent to Masonboro Island (USACE, 2000). Along with the channel realignment, the southern most section of shoreline within Reach III (transects 80 – 85) built seaward ~40 m. It is possible that the inlet realignment occurred prior to the initial dredging of the sediment trap in 1967 because aerial photography was not available to indicate otherwise. However, the most plausible scenario was that the inlet migration and subsequent development of a 40 m accretionary bulge was a direct response to the excavation of over 290,000 m^3 of sand from the sediment trap. The remainder of Reach III and Reach II eroded similar amounts (~22 m) during the 13-year period. There was also no apparent influence of the Pleistocene headland (transect 55) on the shoreline near the southern end of Reach II (Figure 16C).

1975 to 1993

Between 1975 and 1982, no significant storms impacted Masonboro Island, but in 1981 in an attempt to prevent sand from entering the inlet from the south and maintain a navigable channel, a 1 km long rock jetty was completed along the southern shoulder of Masonboro Inlet. During this project, approximately 1,000,000 m^3 of sand were removed from the inlet and placed along Wrightsville Beach (USACE, 2000). None of the dredged material was placed along Masonboro Island, and the amount of littoral sediment transported to the south was significantly reduced. The Army Corps of Engineers (2000) reported that the annual sediment deficit along Masonboro Island resulting from the Masonboro Inlet navigation project was 100,000 m^3/yr.

Despite the overall sediment deficit caused by the jetties, the northern most section of Reach I (1,600 m) prograded following the completion of the southern jetty in 1980. The jetty trapped the littoral sediments coming from the south, preventing the sediment from bypassing the inlet. As a result, sand was impounded along the northern section of Masonboro Island adjacent to the jetty (transects 1 – 15), which altered the planform of the island as the fillet developed. Progradation along the newly formed fillet averaged ~23 m, while the southern half of Reach I eroded ~31 m during the same period (1975 to 1982). However, almost all of the progradation (~23 m) occurred within the two years following the completion of the southern jetty in 1980. The initial influence of the fillet in 1982 extended along the northern most 1.6 km of the island, but the fillet gradually influenced larger sections of the shoreline through time (Figure 29). In 1986, the build-up of the fillet was aided by the placement of ~841,000 m^3 of sediment along the north end of the island following inlet dredging (USACE, 2000). All of this sediment was placed within the influence of the fillet, which effectively prevented any of that sediment from being transported to the southern end of the island. By 1993, the influence of the jetties extended to 2.6 km of shoreline, and the shoreline continued to prograde an average of ~33 m between 1982 and 1993. Total accretion (1975 to 1993) along the 2.6 km section of shoreline influenced by the fillet amounted to ~56 m in the 13 years following the completion of the jetty. The rapid development of the fillet following the completion of the jetty has also been described by SAULT *et al.* (1999) who reported a seaward build up of 72 m between 1979 and 1996 when measured along a single transect within Reach I. These values were similar to the nearly 70 m of progradation that occurred between transects 5 and 10 (Figure 18B) between 1981 and 1993.

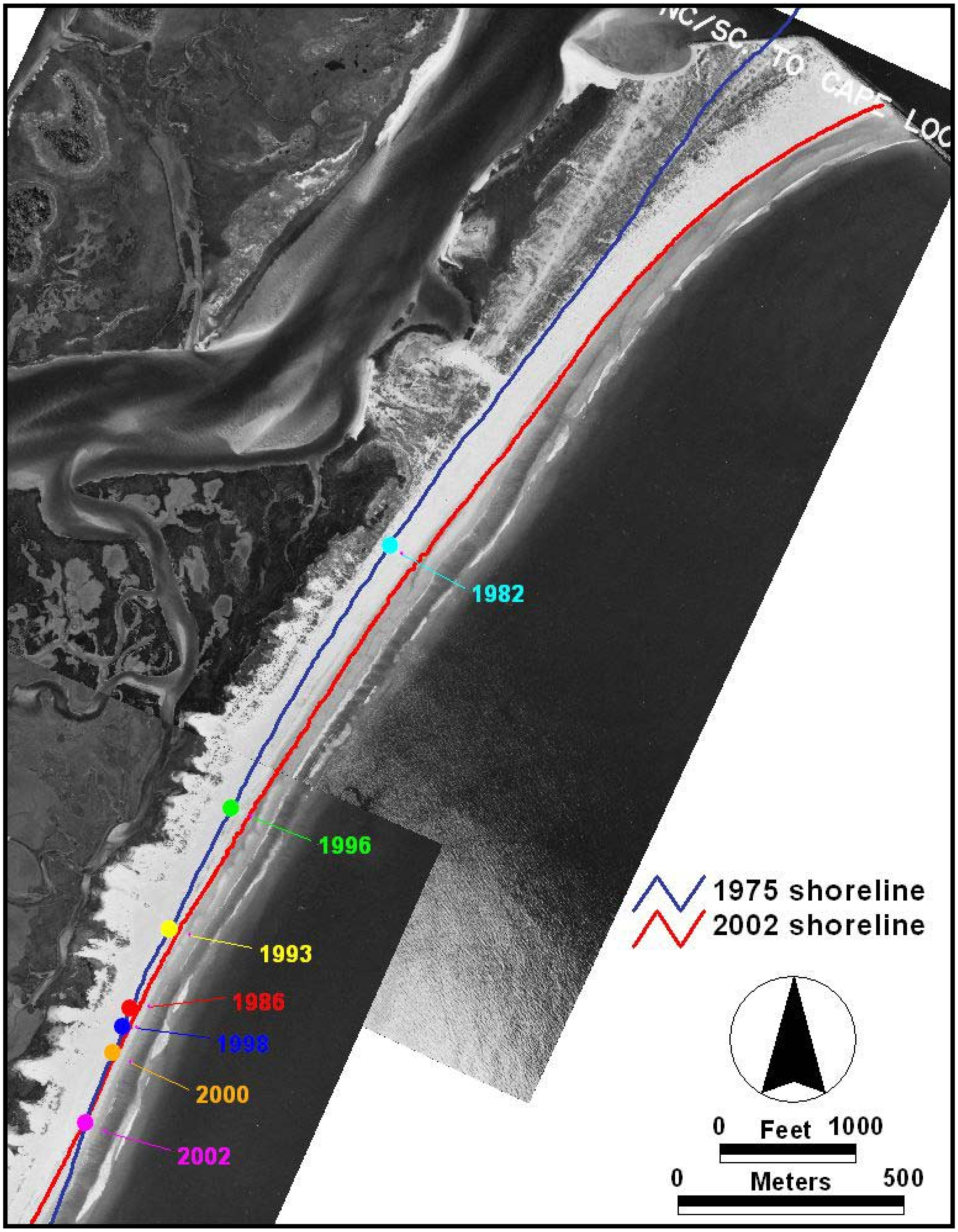

Figure 29. Illustration depicting the range of the fillet influence since the completion of the southern jetty in 1981. The fillet influence covers more than 3,100 m of shoreline. The shorelines are superimposed on 2000 aerial photography.

The central reach of the island continued to erode an average of 35 m between 1975 and 1993; however, during the period between 1975 and 1982, the presence of a small Pleistocene interfluve emerged as a control on shaping the shoreline along the southern end of Reach II. The interfluve remained relatively stable with a net seaward build up of ~1 m despite significant erosion (10-20 m) on the flanks. Only a slight amount of erosion occurred in the vicinity of the headland (Figure 18A), but it is important to note that this value is the average of five transects near the headland of which some were eroding. As a result of the shoreline stability over the headland, a small (100 m wide) protuberance developed along this shoreline segment. Between 1982 and 1993, the same shoreline segment again remained stable (+1 m), but the protuberance appeared to shift slightly farther to the south (Figure 18B). The slight change in the position of the protuberance suggests that the axis of the interfluve was not oriented perpendicular to the shoreline. Therefore, as the island translated landward, the protuberance related to the position of the axis would migrate along the island. Shoreline segments within the remainder of Reach II experienced increasingly greater amounts of erosion with increased distance from the headland (Figure 18B).

Reach III also experienced net shoreline erosion (~25 m) between 1975 and 1982 (Figure 18A); however, erosion rates immediately adjacent to Carolina Beach Inlet were noticeably higher (~76 m) than the average net erosion. Greater erosion rates near the inlet were the result of the removal of sand from the sediment trap within the inlet channel. In 1981, approximately 310,000 m^3 of sediment were removed from Carolina Beach Inlet and placed along Carolina Beach (USACE, 2000). Although this inlet system is complex, sand from the ebb delta migrated into the inlet following the removal of sediment from the inlet channel. Subsequently, littoral sediment from the updrift side of the inlet (Masonboro Island) collected within the ebb delta. In addition, some of the littoral sediments were deposited directly into the sediment basin. Therefore, the south end of Reach III eroded as the sediment trap readjusted to equilibrium. In addition to the removal of sand from the inlet in 1981, a total of 2,083,000 m^3 of sediment were dredged between 1985 and 1991. All of this sediment was placed along Carolina Beach (USACE, 2000). As a result of the continued excavation of the trap, the south end of the island (Reach III) eroded an additional 37 m on average between 1982 and 1993 (Figure 18B), and became the most erosion prone section of the island.

1993 to 1996

The landfall of Hurricanes Bertha (July 22, 1996) and Fran (September 5, 1996) ended the period of storm quiescence that characterized the area for the previous decade. Hurricane Bertha made landfall as a category 1 storm with sustained winds of 137 km/hr and ~1.5 m storm surge. Seven weeks later Hurricane Fran, a category 3 storm, made landfall with sustained wind speeds of 185 km/hr and produced a 3.4 m storm surge. The storm surge exceeded the 100-year flood level, and the southern two-thirds of the island were submerged for 4 to 5 hours (SAULT *et al*., 1999). Both of these storms coupled with the dredging of the adjacent inlets prior to the storms had a significant impact on all three reaches of the island.

Prior to 1993, the northern reach of the island was characterized by significant progradation within the fillet (~4.5 m/yr); however, despite the placement of over 459,000 m^3 of sediment along the northern end of the island, Reach I only prograded 6.6

m (~2.4 m/yr) between 1993 and 1996 (Figure 18C). The amount of accretion along the fillet zone would likely have been greater had the two hurricanes not made landfall near the island. The remainder of the island not influenced by the jetties translated landward, with dramatic amounts of hurricane induced erosion (85 m) concentrated to the south of the Pleistocene interfluve. Following Hurricane Fran, friable, semi-indurated, humate sand was exposed along the shoreline affected by the headland (SAULT *et. al*., 1999; CLEARY, pers. comm., 2004) [Figure 30C]. The significance of the humate sand in relation to the interfluve will be discussed in the following section. Elevated erosion within Reach III, which along some transects (transects 60 – 75) exceeded 100 m between 1993 and 1996, was due to the combined effects of hurricane impacts and the removal of ~880,000 m^3 of sediment in 1995 from Carolina Beach Inlet prior to the storms. In addition to erosion, overwash produced washover fans along the majority of the island, some of which extended 220 m into the estuary (DOUGHTY *et. al*., 2004). SAULT *et al.* (1999) also reported that the overwash events effectively leveled all of the dunes along the southern two-thirds of the island increasing the washover potential.

1996 to 2002

Following Hurricane Fran (1996), the period between 1996 and 2002 was characterized by a brief period (1996 to 1998) of storm inactivity along the island followed by a spate of hurricane activity (1998 to 1999), which included Hurricane Bonnie on August 26, 1998 and Hurricane Floyd on September 16, 1999 (Table 1; Figure 8). Significant shoreline changes occurred along the island during the 1.9 year period following Hurricane Fran (1996). The shoreline within Reach III prograded ~38 m while

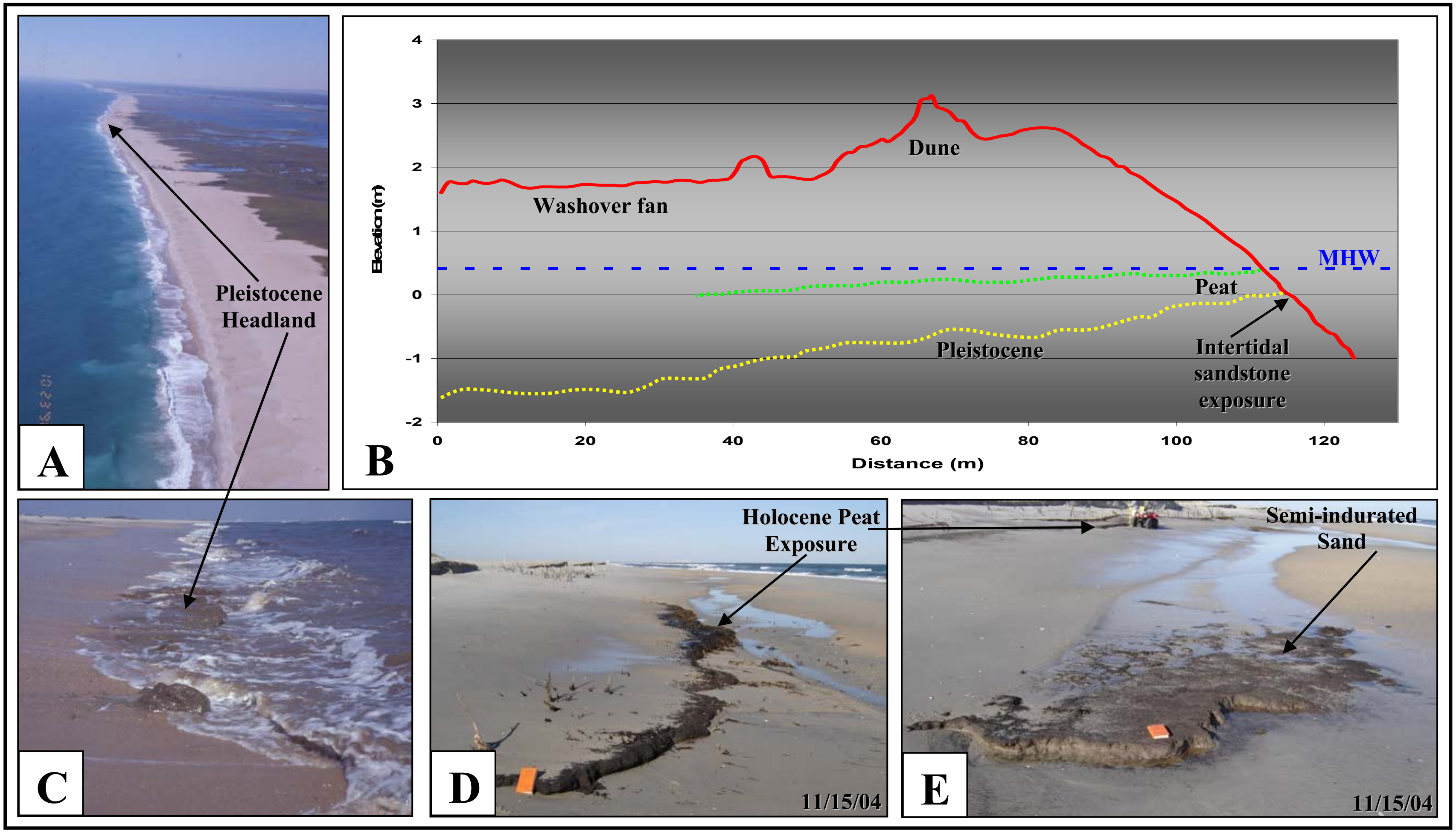

Figure 30. Images and profile illustrating the nature of the Pleistocene sediments that influence the shoreline. (A) Oblique aerial photograph depicting the shoreline protuberance that is cause by the island overriding a Pleistocene interfluve. (B) Profile of the island in the vicinity of the interfluve. (C) Humate sandstone exposed in intertidal zone following Hurricane Fran in September, 1996. (D) Peat exposure along the beach. The peat is stratigraphically higher than the humate sandstone. (E) Remnants of the humate sandstone exposed within the intertidal zone.

the shoreline within Reach II prograded ~19 m. The significant accretion following Hurricane Fran could indicate that large offshore sandbars deposited by the storm were redeposited on the island during fair-weather conditions. In fact, CLEARY (pers. comm., 2004) reported that massive sandbars (Figure 31) were welded onto the southern end of the island as soon as 24 hours after the landfall of Hurricane Fran.

Following the brief period (1.9 yrs) of foredune recovery, Hurricane Bonnie (1998) made landfall followed soon after by Hurricane Floyd (1999). The combined effect of these storms rivaled the impact of Hurricane Fran in 1996 (SAULT *et. al.,* 1999; DOUGHTY *et. al*, 2004). In addition to these storms, both Carolina Beach Inlet and Masonboro Inlet were dredged, which when combined with the storm influence, created significant variations in the shoreline change along the island. The net shoreline change along Reach I remained fairly stable (-0.3 m) during the six years following Hurricane Fran (1996 to 2002). Erosion (~10 m) was limited to the area immediately adjacent to the jetty, while the remainder of Reach I experienced minor amounts of accretion (~7 m) likely due to the placement of over 424,000 m^3 of dredged inlet material along the northern reach in 1998.

Reach II and III, unlike the northern reach, did not have the benefit of renourishment between 1996 and 2002, but did experience shoreline recovery immediately following Hurricane Fran (1996). When accounting for the foredune recovery after Hurricane Fran and the erosion resulting from Hurricanes Bonnie and Floyd, Reach II had net shoreline erosion that amounted to ~11 m. Shoreline erosion within Reach III was more complex and consisted of a section of accretion (~15 m) at the northern end and a section of erosion (~10 m) adjacent to Carolina Beach Inlet (Figure 20). It is likely that the higher

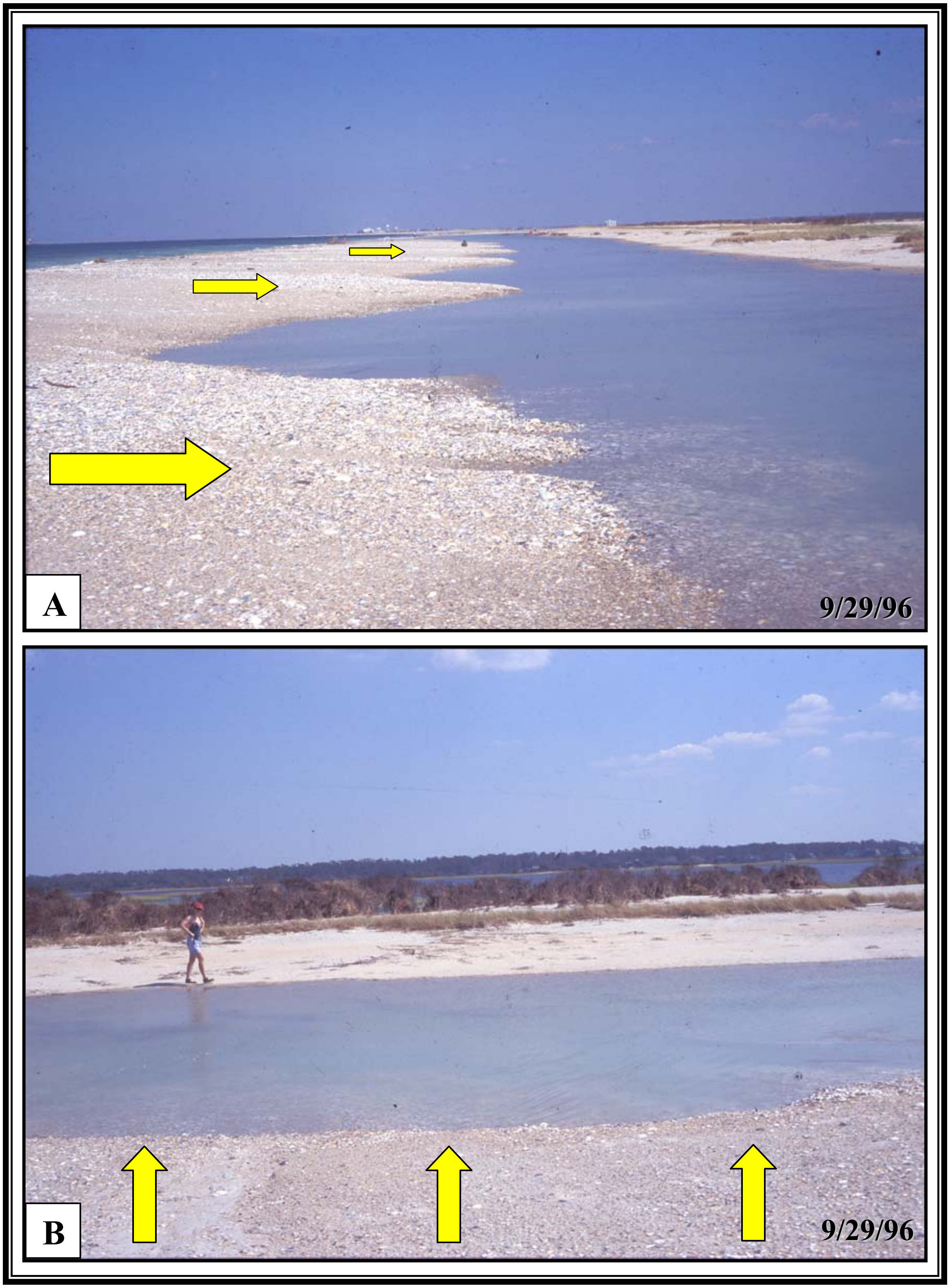

Figure 31. (A) South view of large sandbar migrating onto the shoreline within Reach II following Hurricane Fran (1996). (B) West view of migrating sandbar following Hurricane Fran. Arrows indicate direction of sand transport. Photographs were taken 24 days after Hurricane Fran made landfall. Photographs courtesy of William J. Cleary.

erosion rates near Carolina Beach Inlet were related to the removal of ~917,000 m^3 of sand from the sediment basin (USACE, 2000) and related to sand impoundment within the washover terraces during the hurricanes. DOUGHTY *et. al.* (2004) reported that a washover terrace spanned the entire length of Reach III and penetrated into the estuary by as much as 75 m along the southern most portions of the island. Assuming an average thickness of 0.3 m, the net volume of sand deposited on the terrace within Reach III amounted to ~85,000 m^3 between 1996 and 2002. This value is likely an underestimation of the amount of material deposited on the terrace; however, this estimate coupled with the volume of sand (~917,000 m^3) dredged from the inlet in 1998 provides a sense of the sediment deficit along Reach III.

Summary of Net Change (1938 to 2002)

Data from this study, as well as previous studies by HOSIER and CLEARY (1979), CLEARY and HOSIER (1994), MOUNDALEXIS (1998), SAULT *et. al*. (1999), REIMER (2004), and DOUGHTY *et. al*. (2004), indicate that major storms and inlet modifications played an integral part in the recent evolution of Masonboro Island. The low barrier profile made the island increasingly susceptible to overtopping, and subsequent overwash events transported large volumes of sand into the estuary, ultimately translating the island landward. In addition, the chronic erosion along the southern two-thirds of the island precluded the development of new dunes (CLEARY and HOSIER, 1994). However, the impact of each storm on shoreline change varied greatly along the island primarily due to the modification of adjacent inlets.

One could argue that the opening and continuous maintenance of Carolina Beach Inlet along with the stabilization and maintenance of Masonboro Inlet had the largest influence on the recent evolution of the island. Prior to the opening of Carolina Beach Inlet in 1952, the barrier segment within Reach III was relatively stable (USACE, 2000). The opening of the inlet destabilized the southern end of the island by entraining the littoral sediment within the ebb and flood tidal deltas, effectively increasing the sediment deficit. In addition, a total of ~4,415,000 m^3 of sand were periodically dredged from the inlet, all of which was artificially bypassed to Carolina Beach (USACE, 2000). The southern portion of the island had a negative sediment budget and became the most erosive section of the island, with ~164 m of erosion recorded along Reach III between 1938 and 2002.

The differential shoreline change that occurred north of Carolina Beach Inlet during each time period is visible in the historic aerial photography. The sequence of images in Figure 32 depicts the response of the island to the opening of the inlet, the subsequent sand bypassing of sediment to Carolina Beach and Wrightsville Beach, as well as shoreline change resulting from major storm influences. The 1938 shoreline was characterized by a continuously scarped but well vegetated dune system, and according to the Army Corps of Engineers (2000) was relatively stable. However, following the opening of Carolina Beach Inlet (1952), the landfall of Hurricane Hazel (1954), and the impact of the Ash Wednesday Storm (1962), the previously intact dune system was breached, washover fans penetrated ~160 m into the estuary, the island translated landward, and the shoreline eroded ~35m. Then, with the exception of Hurricane Diana (1984), there were no significant storms to impact the island between the time that the 1962 and 1986 photographs were taken. However, the shoreline continued to erode (~40

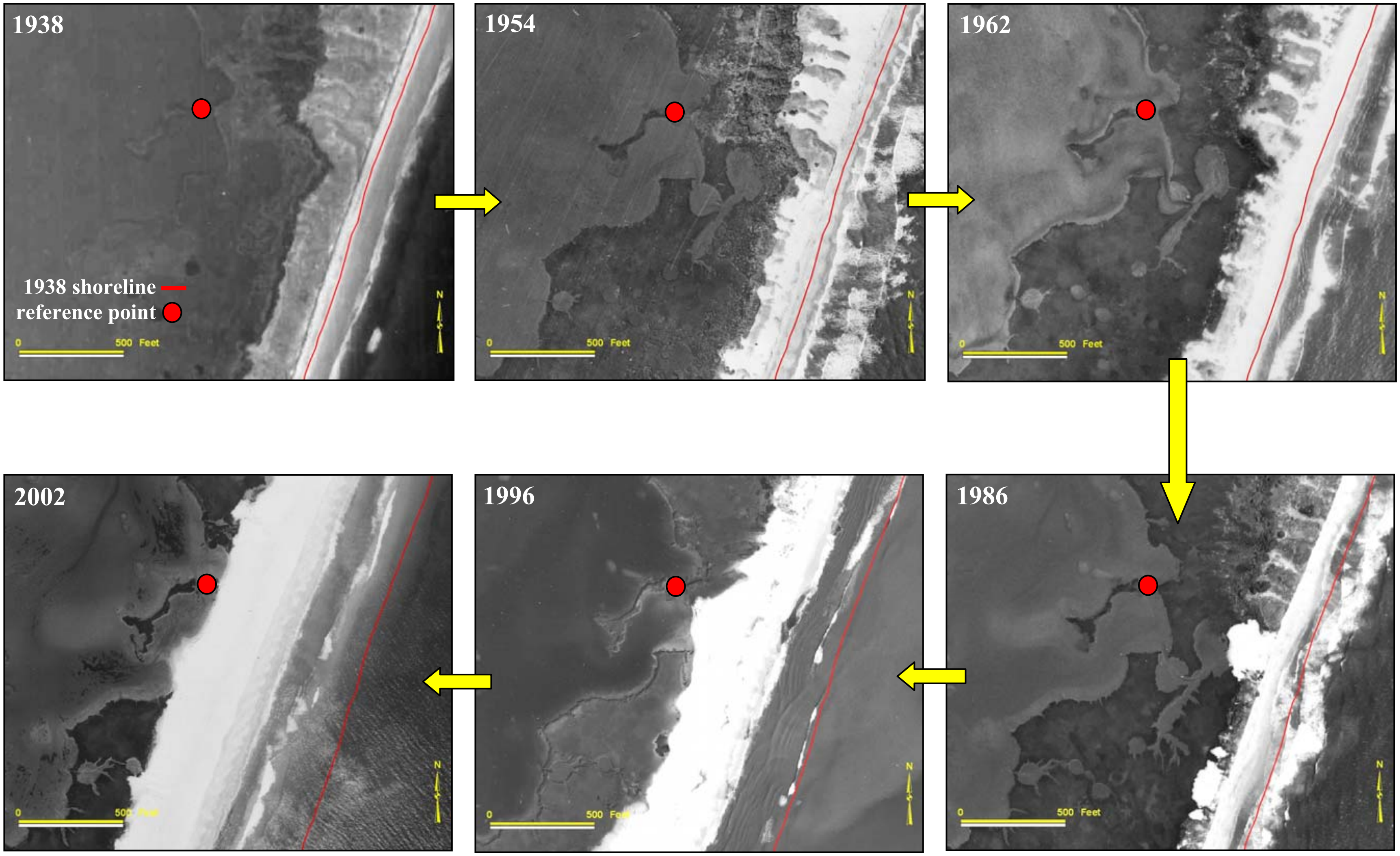

Figure 32. Sequence of shoreline change along a representative section of Reach III (south end of the island) spanning the period of 1938 – 2002. Erosion along this section of Masonboro Island was in excess of 160 m during this period. The 1938 shoreline and a point of reference are indicated in red on each photo.

m) as a result of the sediment deficit produced by the jetty system at Masonboro Inlet and the periodic dredging of the sediment trap within Carolina Beach Inlet. In response to Hurricanes Fran (1996), Bonnie (1998), and Floyd (1999), the entire dune system was breached and this section of Reach III translated landward ~120 m (Figure 32). Between 1938 and 2002, the northern portion of shoreline within Reach III eroded ~160 m, which is greater than the entire width of the island (Figure 32).

Shoreline change within Reach I was very different than the southern end of the island. The net shoreline change within Reach I amounted to an erosion of ~43 m between 1938 and 2002; however, this value is misleading because the shoreline within Reach I was primarily erosive (~82 m) between 1938 and 1975 and mainly progradational (~39 m) between 1975 and 2002. The initial period of erosion (1938 to 1975) was due primarily to the breaching of the spit during Hurricane Hazel (1954) and the increased sediment deficit resulting from the construction of the jetty (1966) along the northern shoulder of Masonboro Inlet. However, following the completion of the southern jetty in 1981, the shoreline within Reach I was primarily progradational. Between 1975 and 2002, the shoreline within Reach I prograded an average of ~39 m with some areas immediately adjacent to the inlet building seaward as much as 100 m. After the south jetty was completed, an accretionary zone (fillet) quickly developed along the northern end of the island in the lee of the jetty. The entrainment of sediment within the fillet was a function of the northern transport of littoral sands and sand deposited by wave refraction around the ebb tidal delta. In addition, a total of 5,352,000 m^3 of sediment was periodically dredged from the Masonboro Inlet, and of that sediment only 28% was placed along the northern end of Masonboro Island (USACE, 2000). However, all of the sediment artificially bypassed to the island was placed within the influence of the jetty, which prevented the sand from being transported to the southern two-thirds of the island. Therefore, even though a fillet was produced on the lee side of the jetty, the stabilized inlet still produced a sand deficit for Reach II and III.

Short-term Change

Regional Distribution of Coquina and Humate Sand

In addition to the impacts related to storms and inlet modification, a small Pleistocene interfluve has exerted localized control on the morphology of the island near the southern end of Reach II (Figure 2). Historic aerial photography (1975 to 2002) suggests the segment of the island perched on top of the headland has historically been more resistant to erosion than adjacent reaches, and as a result, a shoreline protuberance was often visible along the southern portion of the island (Figure 30A). Larger headland areas with similar influences to the coastline are not uncommon to the North Carolina coast (RIGGS *et al*., 1995; CLEARY *et al*., 1996) and include locations such as Fort Fisher, New Inlet, and Roanoke Island. Various erosion resistant facies of the Neuse Formation that include a well-lithified coquina (calcarenite) and semi-indurated humate sand frequently affect shoreline change and coastal morphology.

Coquina is sporadically exposed throughout the region in places such as Fort Fisher and Snow's Cut (Figures 4, 5 and 7) and also forms much of the nearshore hardbottoms that stretch from Masonboro Island to Kure Beach (CLEARY *et al*., 1999). Some sections of the mainland along the Intracoastal Waterway that are directly landward of the headland bear the names John's Rock, Pickett Rock, and Peden Point, which are indicative of some type of well-indurated material in the area. Prior to extensive development of the mainland area the coquina was exposed along Peden Point (CLEARY, pers. comm., 2004), and large clasts of the coquina can be found on the nearby dredge material islands that border the Atlantic Intracoastal Waterway along the aforementioned areas. There were no exposures of the coquina along the intertidal beach; however, large boulders (~20 kg) of coquina were frequently recovered from the beach and washover terraces in the vicinity of the headland. Although there was no coquina recovered in the shallow estuarine cores (2 to 6 m), the presence of nearshore coquina hardbottoms, the reported exposure of coquina at Peden Point, and the general abundance of the coquina in the region suggests that this unit likely underlies the island.

Humic-rich semi-indurated sand was frequently found in close proximity to the coquina at Fort Fisher and Snow's Cut (Figure 4), and a cursory examination suggests that the humate sand is stratigraphically higher than the coquina. Isolated outcrops of the humate sand were also found within the intertidal zone along the southern end of Reach II after being exhumed by Hurricane Fran in 1996 (CLEARY, pers. comm., 2004). DOCKAL (1996) reported that the humate sand and coquina differ as a result of post depositional diagenesis whereby the carbonate material in the coquina was dissolved and subsequently enriched with humate and ferruginous material. The petrographic data show that the composition of the sand comprising the coquina and humate sand facies were very similar when the data were normalized for the presence of carbonates (Figure 26). Quartz grains in the coquina and humate sand found along Snow's Cut were also very similar in size (~1 phi). However, the quartz in the humate sand found 7 km to the north at Friendly Lane (Figure 4) was finer grained (2-3 phi) than quartz grains found at

Snow's Cut (Figure 33), which may suggest a different environment of deposition. It is possible that the quartz within the humate sand facies is the result of aeolian deposition of dunes on top of the coquina during low sea level stands. The fine grained quartz dunes were then likely colonized by vegetation (forest or pocosin) and humate materials were subsequently translocated through the soil. It is also plausible that the fine quartz sand represents submarine shoal deposits. However, the depositional environment of the Neuse Formation and the subsequent diagenesis of the differing sedimentary facies are beyond the scope of this paper. Regardless of formation, previous studies (RIGGS *et al*., 1995; CLEARY *et al*., 1999) reported that the coquina and humate sand facies had a direct impact on places like Fort Fisher and Kure Beach in regards to shoreline change and sediment composition. It is similarly thought by this author that the coquina and humate sand facies have a similar influence on the small section of Masonboro Island perched over the headland.

Petrology

It is possible that the degradation of the coquina and subsequent bypassing of the coarse grained quartz sand and shell hash to the island accounts for the coarse grained nature of the sediments. The vast majority of the sediments found along the southern two-thirds of the island are relatively coarse grained (1 phi) with an abundance of shell fragments (Figure 34). The coarse nature of the beach sediments is different than the sediments found along the barriers farther north. For example, undeveloped Hutaff Island, located 17 km north of Masonboro Island, is dominated by fine grained quartz

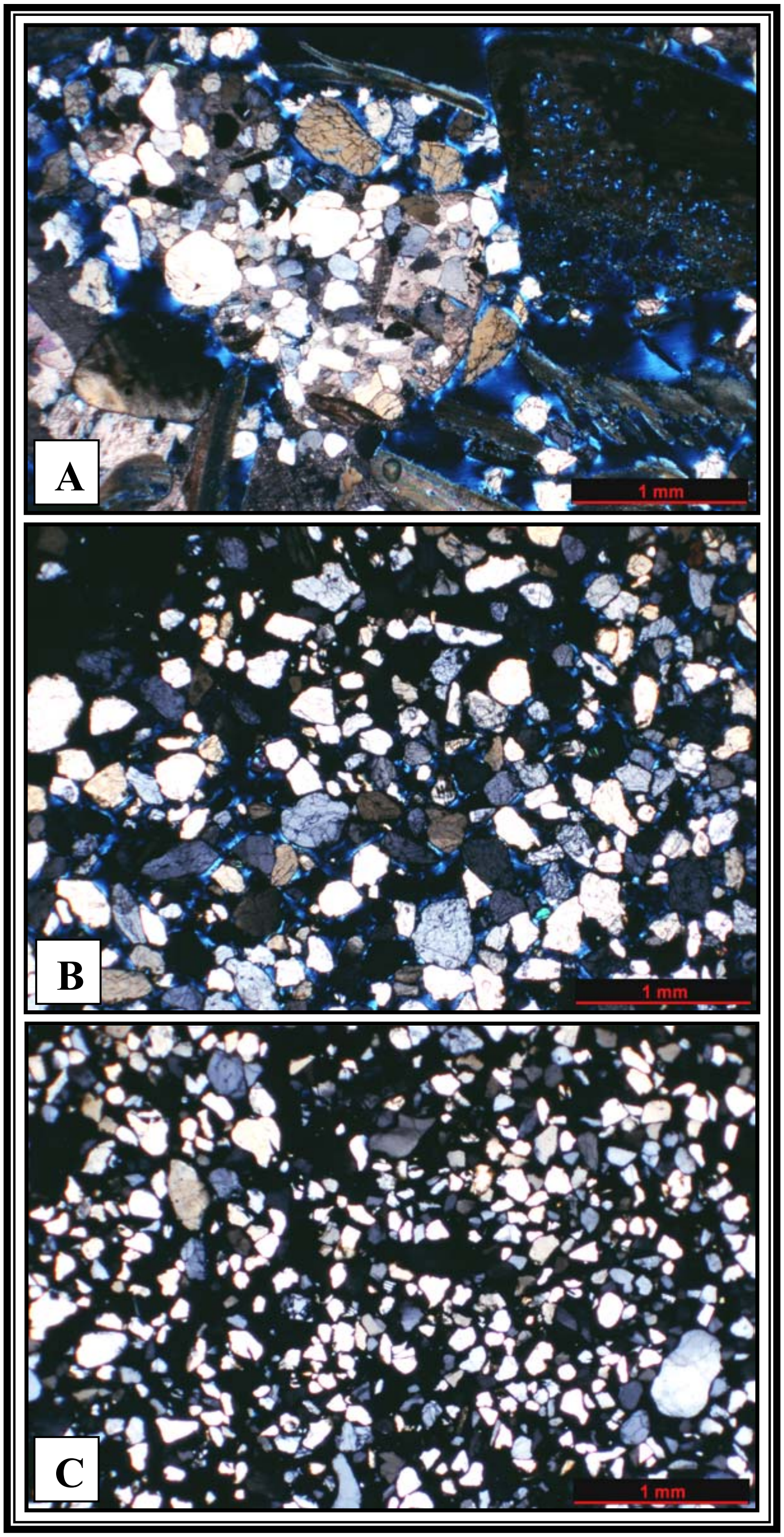

Figure 33. Representative photomicrographs of humate sand and coquina. (A) Photomicrograph of Snow's Cut coquina cemented with spar calcite. (B) Photomicrograph of Snow's Cut humate sand. (C) Photomicrograph of Friendly Lane humate sand. Note that quartz grains at Snow's Cut are considerably larger than quartz grains found at Friendly lane.

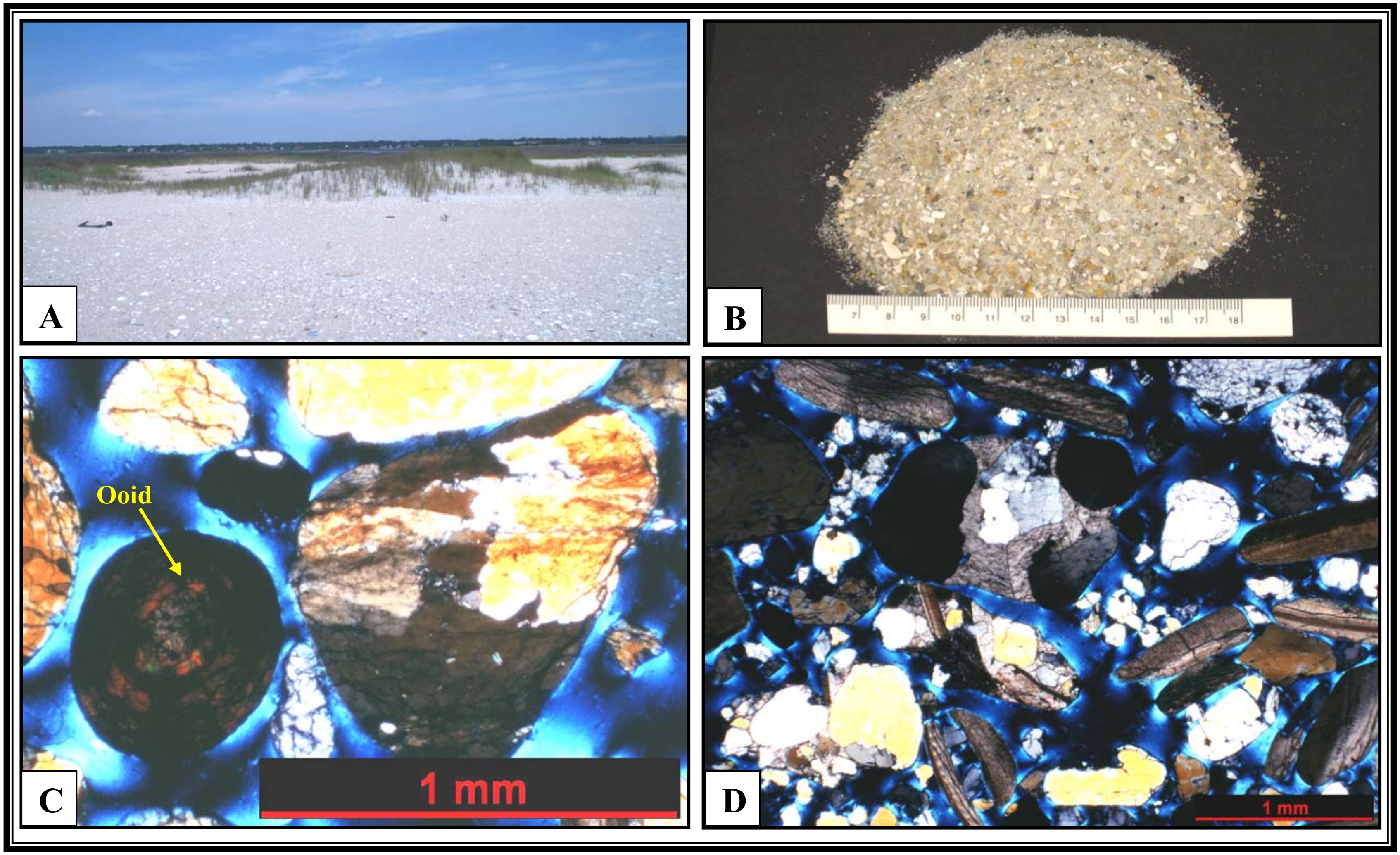

Figure 34. (A) Image of coarse grained beach sediments in the vicinity of the Pleistocene headland (transect 7). (B) Close-up image of coarse grained sediments collected from transect 7. (C) Photomicrograph of an ooid deposited on the berm near the headland. (D) Photomicrograph of coarse grained sediments that characterize the sediments deposited near the headland.

sands with only trace amounts of carbonate material (MCGINNIS, 2004). The likely reason for the difference is due to distinctly different offshore lithologies in these two areas. The shoreface off Hutaff Island consists of an easily eroded Oligocene siltstone/sandstone (MCGINNIS, 2004; DOUGHTY *et al.,* 2004) that provides fine grained quartz sediments. In contrast, the shoreface off of Masonboro Island is geologically more complex. The Oligocene siltstone/sandstone is mainly limited to the northern portions of the shoreface, while the majority of the shoreface off of Reach II and III consists of a Plio-Pleistocene limestone. Overlying the limestone in many areas is a coarse grained carbonate rich Pleistocene coquina that extends from the shoreface off Reach II south to Fort Fisher (CLEARY *et al*., 1999). In all likelihood, the coarse grained sand and shell gravel deposited along the southern two-thirds of the island were derived from the breakdown of the coquina.

A petrologic analysis of the sand and gravel sediments found on the berm near the headland as well as the analysis of coquina found in the intertidal zone indicates that the coquina is a likely source for the sediment found along the southern portion of the island. Modal analysis of sediment recovered from the berm and washover fans indicated that the composition and grain size of this material is remarkably similar to the coquina. In addition, pebble-size clasts of the coquina were frequently identified in the samples recovered from the beach (Figure 27).

The coarse grained sediment derived from the coquina had a major impact on the development and recovery of dunes within Reach II and III (CLEARY and HOSIER, 1994). CLEARY and HOSIER (1994) reported that the fine grained material deposited in the washover fans and terraces was winnowed out from the backshore, and this material accumulated to form the small (<1 m) embryo dunes that sporadically cover Reach II and III. The remaining deflated portion of the sediment was simply too large to be transported by aeolian processes. As a result, the remaining coarse grained material "armored" the underlying sediments and prevented the transport of additional fine grained material (CLEARY and HOSIER, 1994). Each washover event further reduced the dune coverage, lowered the barrier profile, and transported sediment across the island into the lagoon.

Shoreline Change

The Pleistocene coquina and humate sand may have also affected erosion within a small (1.7 km) section of the shoreline at the southern end of Reach II as this section of the island became perched on top. Long-term analysis indicated that between 1975 and 2002 this section of shoreline eroded ~5 % less than the surrounding shoreline within Reach II, which produced a small (100 m wide) protuberance along the shoreline. Analysis of short-term shoreline change data (September, 2003 to October, 2004) from the small section of shoreline perched on the interfluve indicated that the wet-dry line within Zone II (Figure 10) eroded ~42 % slower than in Zones I and III. The higher recession rates of the wet-dry line along the flanks of the headland influenced shoreline indicated that the slope of the foreshore was flattened and the barrier's profile was lowered in elevation. However, analysis of shoreline erosion based on MHW (NAVD 88) suggests that the amount of erosion differed by <1 % (Figure 21A). This suggests that calculating shoreline change based on the position of the wet-dry line may not be the most accurate method due to the fact that the elevation of the wet-dry line changes based on the extent of wave run-up and wave height. In contrast, shoreline change data based on a set vertical datum (NAVD 88) are not influenced by the distance waves run up the beachface.

Similar to shoreline change, the volume of material eroded from the shoreline in the vicinity of the headland was ~60 % less than the amount eroded from the flanks between September 2003 and October 2004 (Figure 21A). This would suggest that the profile of the barrier perched over the headland was higher than the adjacent profiles, which limited the amount of overwash during storm events. However, profile data do not suggest that the profile of the headland influenced shoreline is higher than the adjacent profiles (Appendix A and B). This may suggest that the chronic erosion that characterizes the southern end of Reach II eroded the upper portion of the headland and lowered the barrier profile. Subsequently, the section of the island in the vicinity of the headland translated landward as the headland influence diminished.

Despite the differential erosion, the entire section of the barrier profile within the southern end of Reach II was lowered between September 2003 and October 2004 (Appendix A and B). The annual volume of sand lost per kilometer along this section of the island (Figure 10) amounted to ~23,800 m^3 when calculated above MLW. Transect 55 was selected to represent the average changes in barrier profile that occurred in the vicinity of the headland. Representative profiles of the island surveyed near transect 55 (Figure 9) between September, 2003 and October, 2004 were combined with profile data from SAULT (1999) that spanned the period between 1972 and 1997. These combined data indicate that the section of the island just south of the headland was lowered in elevation, stripped of existing dune coverage, and translated landward more than one island width during the 32-year period (Figure 35).

Extent of Pleistocene Headland

The geologic framework of the island has a temporal and spatial influence on shoreline change and barrier profile based on the variability of shoreline translation and erosion. The small headland that has a localized affect on shoreline change is composed of humate sand and coquina based on the intertidal exposure of the humate sand following Hurricane Fran (1996), the presence of large coquina boulders (~20 kg) along the foreshore, and the documented exposures of coquina along the shoreface (CLEARY, 1999). The semi-indurated humate sand that composed the headland was more resistant to erosion than the peat and inlet-fill material that underlies the barrier segments adjacent to the headland. Consequently, between 1975 and 2004, adjacent sections of the shoreline eroded more (~111 m) than the headland influenced section (~87 m) resulting in a protuberance that was evident in the barrier's planform (Figure 30A). In response, wave energy was increasingly focused on the protuberance as this feature developed. Since 1975, the island has continued to translate over the headland and in the process eroded the humate sand.

CLEARY (pers. comm., 2004) observed the humate sand exposed within the intertidal zone following Hurricane Fran (1996); however, since that time there have been no reported exposures of the humate sand along Reach II. It is possible that the humate sand exposure was buried by the deposition of sediment that was previously eroded from the foreshore during Hurricane Fran. Another possible scenario is that the section of the

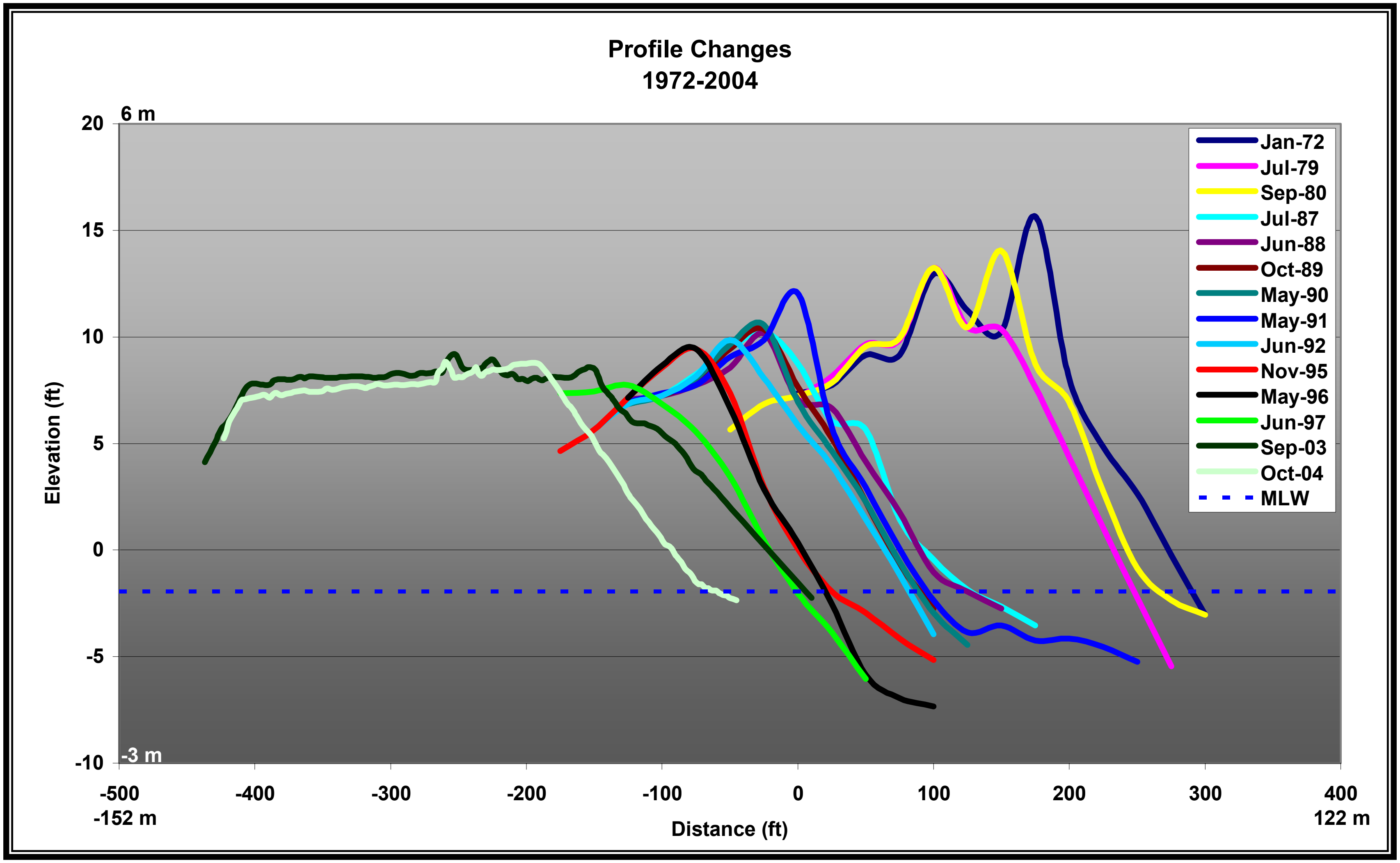

Figure 35. Illustration of changes in barrier profile near transect 55 (see Figure 9) between 1972 and 2004. This section of the island is located 1 km south of the headland. Note that the island has translated landward more than one island width, the dunes have been planed off, and the elevation of the beach platform has been reduced.

island perched on top of the headland translated over the topographically highest point of the humate sand, and the humate sand that was exposed within the intertidal zone was eroded. Consequently, the only remaining portion of the humate sand facies was the lower unlithified sand that remained relatively un-enriched with humate material. In fact, poorly indurated quartz sand with minor amounts of humate material was exposed within the intertidal zone at the southern end of Reach II (Figure 30E). A cursory examination of the exposure indicated that it consisted of well-sorted fine-grained quartz sand (~2 phi), trace amounts of carbonates (<5 %), and minor amounts of humate material. This exposure may represent the lower unlithified portion of the humate sand. Therefore, it is plausible that the southern portion of Reach II has completely translated over the humate sand, and the influence the humate sand had on the morphology of the island has diminished.

The idea that the shoreline within Reach II translated over the topographically highest portion of the headland is supported by the absence of the humate sand in the estuarine cores. Based on limited core data (Figure 22 – 25), the Pleistocene surface appears to be a portion of an ancient drainage network. The ridges or interfluves represent the elevated portions of the old landscape that eventually formed the headland as the barrier island migrated landward. The thinnest portions (~0.5 m) of the estuarine fill are located over a paleo-interfluve, which is believed to extend from Peden Point to the headland-influenced portion of the island (Figure 36). The depth of the estuarine fill increases to ~4 m on either side of the interfluve. Therefore, if the humate sand developed on top of an ancient, undulating, topographic surface, it is possible that the humate sand still exists

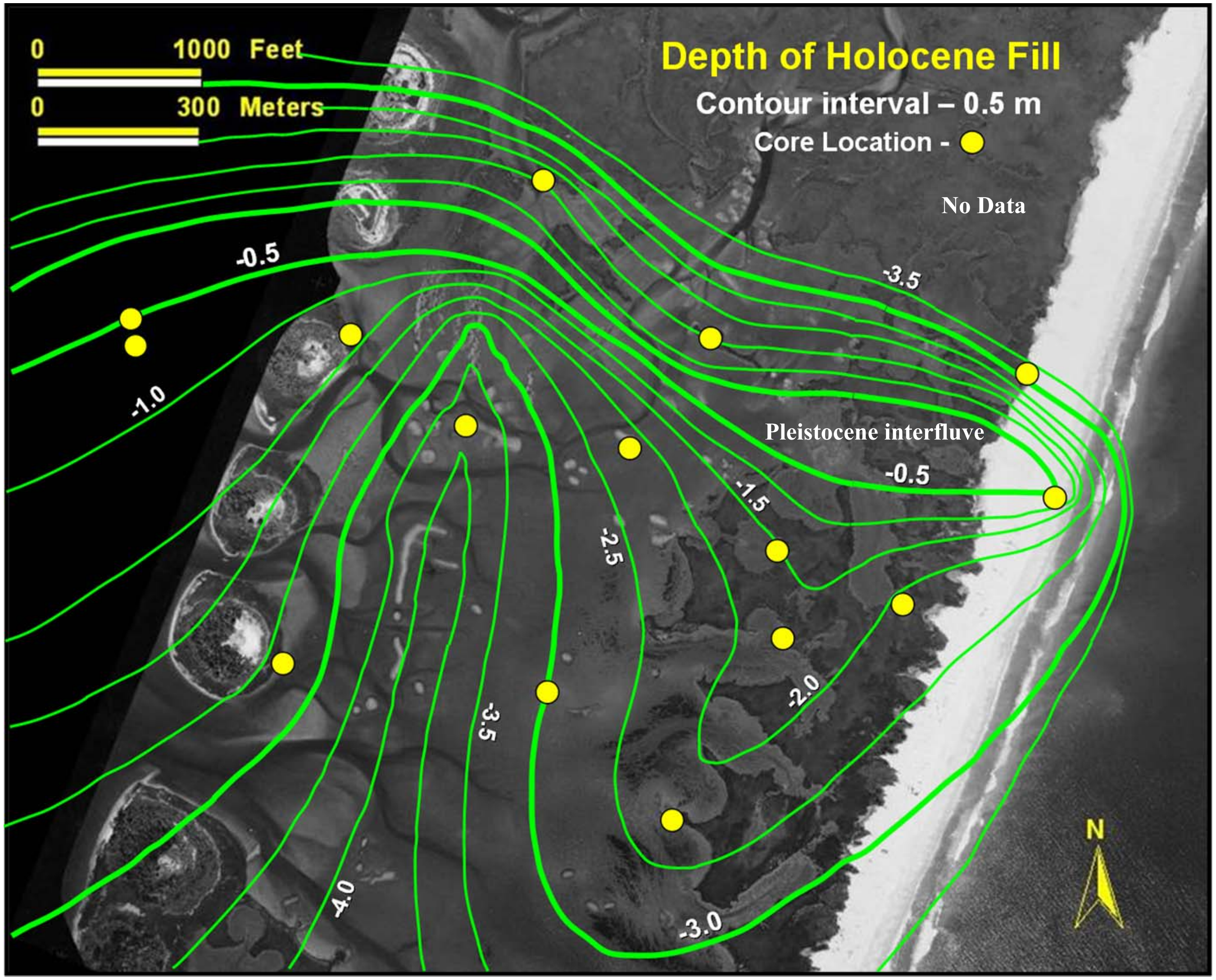

Figure 36. Isopach map depicting possible depth of Holocene fill in the area of a small Pleistocene interfluve.

behind the headland-influenced section of the shoreline but lies at depths not penetrated by the shallow cores (2 to 6 m) retrieved from the estuary.

The location of the headland underlying the southern end of Reach II changed (1975 to 1993) as the barrier migrated over the diverse paleo-drainage network. The change in position of the headland influenced shoreline accounts for the slight variability reported in the shoreline erosion data for the period between 1975 and 1993. The shoreline influenced by the headland between 1975 and 1982 was in the vicinity of transect 50 (Figure 18A); however, the data suggest that between 1982 and 1993 the headland influence was near transect 55 (Figure 18B). The variation in the position of the headland influence on the shoreline supports the idea that the southern portion of Reach II translated over an ancient topographic surface characterized by ridges and valleys. It is also likely that the shoreline will continue to override portions of the interfluve as the island continues to translate landward, but the influence that ridge has on the shoreline will be determined by the type of sediments present and how well the material is lithified.

CONCLUSIONS

The shoreline change of Masonboro Island since 1938 is a function of the modification of adjacent inlets, the underlying geologic framework, and the impacts of tropical and extra-tropical storms. The island is situated along the major storm tracks and is frequently overtopped by high energy storm events. Notable storms including Hurricane Hazel (1954), the Ash Wednesday Storm (1962), Hurricane Fran (1996), Hurricane Bonnie (1998), and Hurricane Floyd (1999) had dramatic impacts on shoreline change since 1938. The degree of influence that these storms had on the island was largely determined by the pre-storm condition of the island and the influence of the adjacent inlets.

One of the most significant controls on the recent evolution of the island was the effect of the two adjacent inlets. Arguable, the single most influential event in the recent history of the island was the artificial opening of Carolina Beach Inlet in 1952. The new inlet was cut across a previously stable section of shoreline and immediately created a sediment deficit along the southern two-thirds of the island. Large volumes of sand were impounded in the flood and ebb tidal deltas. Consequently, the southern end of the Masonboro Island, as well as Carolina Beach immediately south, began to erode and eventually translate landward. In effort to maintain a renewable source of sand for Carolina Beach, a sediment trap was dredged within the inlet channel. The sand that collected in the sediment trap was periodically bypassed to neighboring Carolina Beach, which further exacerbated the erosion along the southern end of Masonboro Island. As a result of the increased sediment deficit, the boundaries of the chronic erosion zone that characterized Reach III expanded to include the southern two-thirds of the island between 1952 and 2004.

Masonboro Inlet was also very influential in the development of the island (1966 to 2004) and unlike Carolina Beach Inlet, had both positive and negative impacts on shoreline change as a result of the dual jetty system. The completion of the northern jetty in 1966 reduced the amount of littoral sediment transported from the north, and coupled with the negative influence of Carolina Beach Inlet, reduced the sediment budget along the island. Fifteen years later, the southern jetty was completed (1981), and between

1981 and 2004, a fillet formed adjacent to the jetty. The impoundment of sand within the fillet widened the north end of the island ~39 m, and as a result, this area had significantly more and higher dunes than any other section of the island. But the jetties that stabilized the inlet prevented the transport of littoral sediments to the central and southern segments of the island. The end result of the two modified inlets was the development of three distinct erosional reaches along the island with progradation occurring to the north, extensive erosion occurring to the south, and a transition zone between the two.

As the island migrated landward between 1975 and 2004, a small Pleistocene headland at the southern end of Reach II exerted localized control on the morphology of the island. The interfluve was composed of erosion resistant humate sand. Additional exposures of the humate sand along Fort Fisher and Snow's Cut are typically found overlying coquina. It is hypothesized that the interfluve composed of the humate sand is underlain by the coquina that characterizes portions of the shoreface off the southern two-thirds of the island.

The shoreline perched on top of this headland eroded ~5 % less than the adjacent shoreline sections. However, chronic erosion eventually eroded the humate sand, lowered the barrier profile, and translated the island landward. In the aftermath of Hurricane Fran (1996), the uppermost portion of the humate sand that was exposed within the intertidal zone was eroded, and consequently the only remaining portion of the humate sand is the lower poorly lithified section that is periodically exposed within the intertidal zone.

This study provides examples of how long-term and short-term changes have been dictated by the modification of adjacent inlets and the localized influence of the underlying geologic framework. Superimposed upon these two variables are the impacts of tropical and extra-tropical storms. The major impacts of these three variables are as follows: (1) The opening of Carolina Beach Inlet in 1952 decreased the sediment budget along the entire length of the island by impounding sand within the channel. The sediment deficit increased as a result of the placement of all of the artificially bypassed sediment on Carolina Beach. (2) The northern jetty (1966) and the southern jetty (1981) that stabilize Masonboro Inlet decreased the sediment budget along the southern two-thirds of the island but increased the sediment budget within the fillet along Reach I. (3) A Pleistocene headland composed of humate sand exerted a localized control on a small section of shoreline at the southern end of Reach II. The erosion resistant headland produced a shoreline protuberance as the shoreline eroded. The barrier segment perched over the headland eventually translated landward as a result of chronic erosion and a lowered barrier profile. (4) Shoreline changes in response to chronic storm impacts are partially dictated by the influence of the inlets and geologic framework.

Masonboro Island provided an exemplary setting to study the behavior of barriers in response to storms and anthropogenic impacts without the complications associated with the extensive development that characterize much of the area. Hopefully this study will provide coastal managers insights into the response of an island to inlet modifications and the inherent geologic framework, as well as provide a better understanding of the dynamic and complicated processes of barrier island evolution.

LITERATURE CITED

ANDERS, F.J. and BYRNES, M.R., 1991. Accuracy of Shoreline Change Rates as Determined from Maps and Aerial Photographs. *Shore and Beach*, 59(1), 17-26.

BARNES, J., 1998. *North Carolina's Hurricane History* (Revised & Updated Edition), Chapell Hill, The University of North Carolina Press, 75-172, 205-211.

CLEARY, W.J. 2004. Personal communication.

CLEARY, W.J., JOHNSEN, C.D., JOHNSTON, M.K., and SAULT, M. 1999. Storm Impacts and Shoreline Recovery in SE NC: Role of the Geologic Framework. *Coastal Sediments*, (1), 1799-1813.

CLEARY, W.J., and PILKEY, O. 1996. Environmental Coastal Geology: Cape Lookout to Cape Fear, NC Carolina Geological Society Fieldtrip Guidebook *In: Cleary, W.J. (ed.). Environmental Coastal Geology: Cape Lookout to Cape Fear, NC. 89-128.*

CLEARY, W.J. and HOSIER, P.E., 1994. Morphology and stratigraphy of a transgressive barrier and associated estuarine system: Masonboro Island, North Carolina. *Unpublished Technical Report*. National Estuarine Sanctuary Program. 1-25.

CLEARY, W.J., RIGGS, S.R., and THEILER, E.R., 1993. Barrier, lagoon and shoreface Holocene stratigraphy: Masonboro Island, NC. *Abstracts with Program*, Geological Society of America, Southeastern Section, Tallahassee, Florida, 25(4), 8.

CLEARY, W.J., and HOSIER, P.E., 1979. Geomorphology, Washover History, and Inlet Zonation: Cape Lookout, N.C., to Bird Island, N.C. In: Leatherman, S.P. (ed), Barrier Islands. Academic Press, New York, N.Y. pp. 237-271.

CLEARY, W.J., and THAYER, P.A., 1973. Petrography of carbonate sands on the Carolina continental shelf. *Transactions of the Gulf Coast Association of Geological Societies*, Houston, Texas, (23), 288-304.

CLEARY, W.J. and PILKEY, O.H., 1968. Sedimentation in Onslow Bay. *In: Guidebook for field excursion, Geological Society of America, Southeastern Section, Durham, NC: Southeastern Geology*, Special Publication, (1), 1-17.

CROWELL, M., LEATHERMAN, S.P., and BUCKLEY, M.K., 1991. Historical Shoreline Change: Error Analysis and Mapping Accuracy. *Journal of Coastal Research*, 7(3), 839-853.

DEL GRECO, S. and HINSON, S., (eds). 1998. *Storm Data: and unusual weather phenomena with late reports and corrections*. National Climatic Data Center, Asheville, NC, 40(8), 110-113.

DOCKAL, J.A. 1996. The coquinas of the Neuse Formation, New Hanover County, North Carolina. *In: Cleary, W.J. (ed). Environmental Coastal Geology: Cape Lookout to Cape Fear, NC* . 11-22.

DOLAN, R., FENSTER, M.S., and HOLMES, S.J., 1991. Temporal Analysis of Shoreline Recession and Accretion. *Journal of Coastal Research*, 7(3), 723-744.

DOUGHTY, S.D.; CLEARY, W.J. and MCGINNIS, B.A., 2004. The Recent Evolution of Storm-Influenced Retrograding Barriers in Southeastern North Carolina, USA. *Journal of Coastal Research*, SI 39, p. (in press). Itajaí, SC – Brazil, ISSN 0749-0208

FALLOW, W. and WHEELER, W.H., 1969. Marine fossiliferous Pleistocene deposition southeastern North Carolina. *Southeastern Geology*, 10: no. 1, 35-54.

FOLK, R.L. 1980. *Petrology of sedimentary rocks*. Hemphills, Austin, Texas.

HOSIER, P.E., and CLEARY, W.J., 1977. Cyclic Geomorphic Patterns of Washover on a Barrier Island in Southeastern North Carolina, *Environmental Geology* (2), 23-31.

JACKSON, C.W., 2004. Quantitative Shoreline Change Analysis of an Inlet-Influenced Transgressive Barrier System: Figure Eight Island, North Carolina. Wilmington, North Carolina: University of North Carolina at Wilmington, Master's Thesis, 86p.

JARRETT, J.T., 1977. Sediment budget analysis, Wrightsville Beach to Kure Beach, North Carolina. Proceedings, *Coastal Sediments 1977*. ASCE, New York, 986-1005.

MARCY, D.C., 1997. Influence of inherited geologic framework upon a hardbottom dominated shoreface: Fort Fisher subaerial headland, Onslow Bay, North Carolina. Wilmington, North Carolina: University of North Carolina at Wilmington, Master's Thesis, 123p.

MCGINNIS, B.A., 2004. Late Holocene Evolution of a Retrograding Barrier: Hutaff Island, North Carolina. Wilmington, North Carolina: University of North Carolina at Wilmington, Master's Thesis, 92p.

MILLIMAN, J.D., PILKEY, O.H., and BLACKWELDER, B.W., 1968. Carbonate sediments on the continental shelf, Cape Hatteras to Cape Romain: *Southeastern Geology*, (9), 245-267.

MOUNDALEXIS, ELIZABETH A., 1998. Response of Backbarrier Salt Marshes to Overwash Sedimentation: Masonboro Island, NC. Wilmington, North Carolina: University of North Carolina at Wilmington, Master's Thesis, 98p.

NATIONAL WEATHER SERVICE, 2005. Significant Local Event Archive. National Weather Service Forecast Office – Wilmington, NC. Updated April 19, 2005. http://www.erh.noaa.gov/er/ilm/archive/.

NOAA COASTAL SERVICES CENTER, 2005. Historical Hurricane Tracks. Updated April 22, 2005. http://hurricane.csc.noaa.gov/hurricanes/index.html.

NCDCM, 1998. North Carolina Division of Coastal Management. Department of Environment and Natural Resources. Updated February 4, 2004. http://dcm2.enr.state.nc.us/Maps/ER_1998/SB_Factor.htm.

REIMER, BETH A., 2004. Influences of Major Storm Events on Backbarrier Salt Marsh Change: Masonboro Island, Southeastern North Carolina. Wilmington, North Carolina: University of North Carolina at Wilmington, Master's Thesis, 93p.

RIGGS, S.R., CLEARY, W.J., SNYDER, S.W. 1995. Influence of inherited geologic framework on barrier shoreface morphology and dynamics. *Marine Geology*, (126), 213-234.

SAULT, M., CLEARY, W.J., JOHNSEN, C.D. 1999. Hurricane Impacts and Shoreline Recovery Along Masonboro Island, NC. *Coastal Sediments*, (1), 597-611.

SNYDER, S.W., HOFFMAN, C.W., and RIGGS, S.R., 1994. Seismic Stratigraphic Framework of the Intercontinental Shelf: Mason Inlet to New Inlet, North Carolina. *North Carolina Geological Survey Bulletin No*. 96, 59p.

STEPHENSON, L.W., 1912. The Quaternary Formations, in Clark, W.B., Miller, B.L., Stephenson, L.W., Johnson, B.L., and Parker, H.N. The Coastal Plain of North Carolina. *North Carolina Geological and Economic Survey*, (3), 266-290.

THIELER, E.R., BRILL, A.L., CLEARY, W.J., HOBBS, C.H.(III), GAMMISCH, R.A. 1995. Geology of the Wrightsville Beach, North Carolina shoreface: Implications for the concept of shoreface profile of equilibrium. *Marine Geology*, (126), 271-287.

THIELER, E.R. 1996. Shoreface processes in Onslow Bay. *In: Cleary, W.J (ed.). Environmental Coastal Geology: Cape Lookout to Cape Fear, NC Carolina Geological Society Fieldtrip Guidebook.* 23-32.

U.S. ARMY CORPS OF ENGINEERS, Wilmington District, 1982. Feasibility report and environmental assessment on shore and hurricane wave protection, Wrightsville Beach, NC.

U.S. ARMY COPRS OF ENGINEERS, Wilmington District, 2000. Special Report. Impact of Navigation Projects on Masonboro Island, North Carolina, 42p.

WELLS, B.W., 1944. Origin and development of the lower Cape Fear Peninsula: *Elisha Mitchell Science Society Journal,* 60: no. (2), 129-134.

WELSH, J.M., 2004. Characterization of the evolution of a relocated tidal inlet: Mason Inlet, North Carolina. Wilmington, North Carolina: University of North Carolina at Wilmington, Master's Thesis, 104p.

APPENDIX A: SHORELINE PROFILES OF HEADLAND INFLUENCED SHORELINE

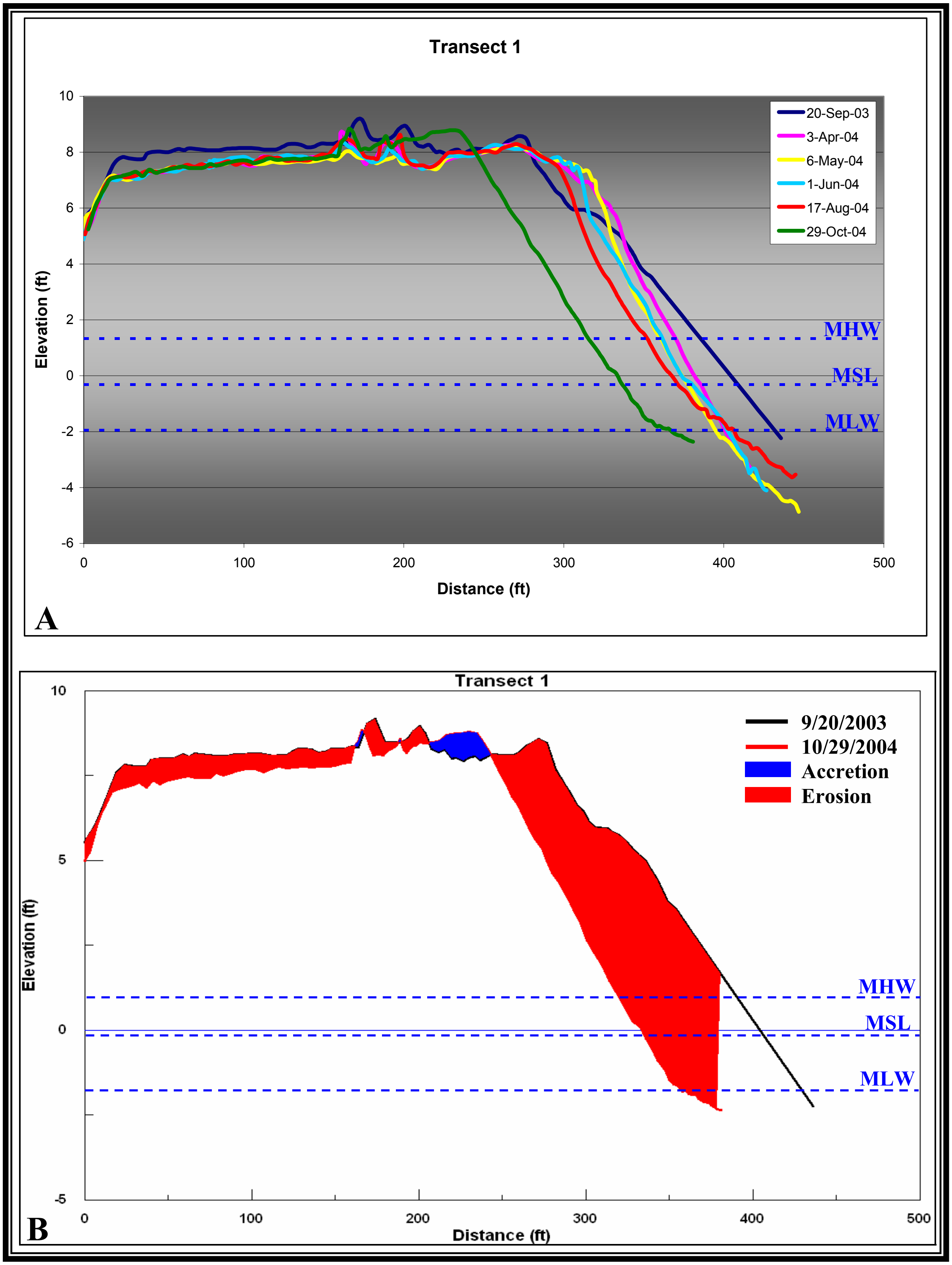

Figure 1: (A) Transect 1 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 1 during the period of September 2003 to October 2004.

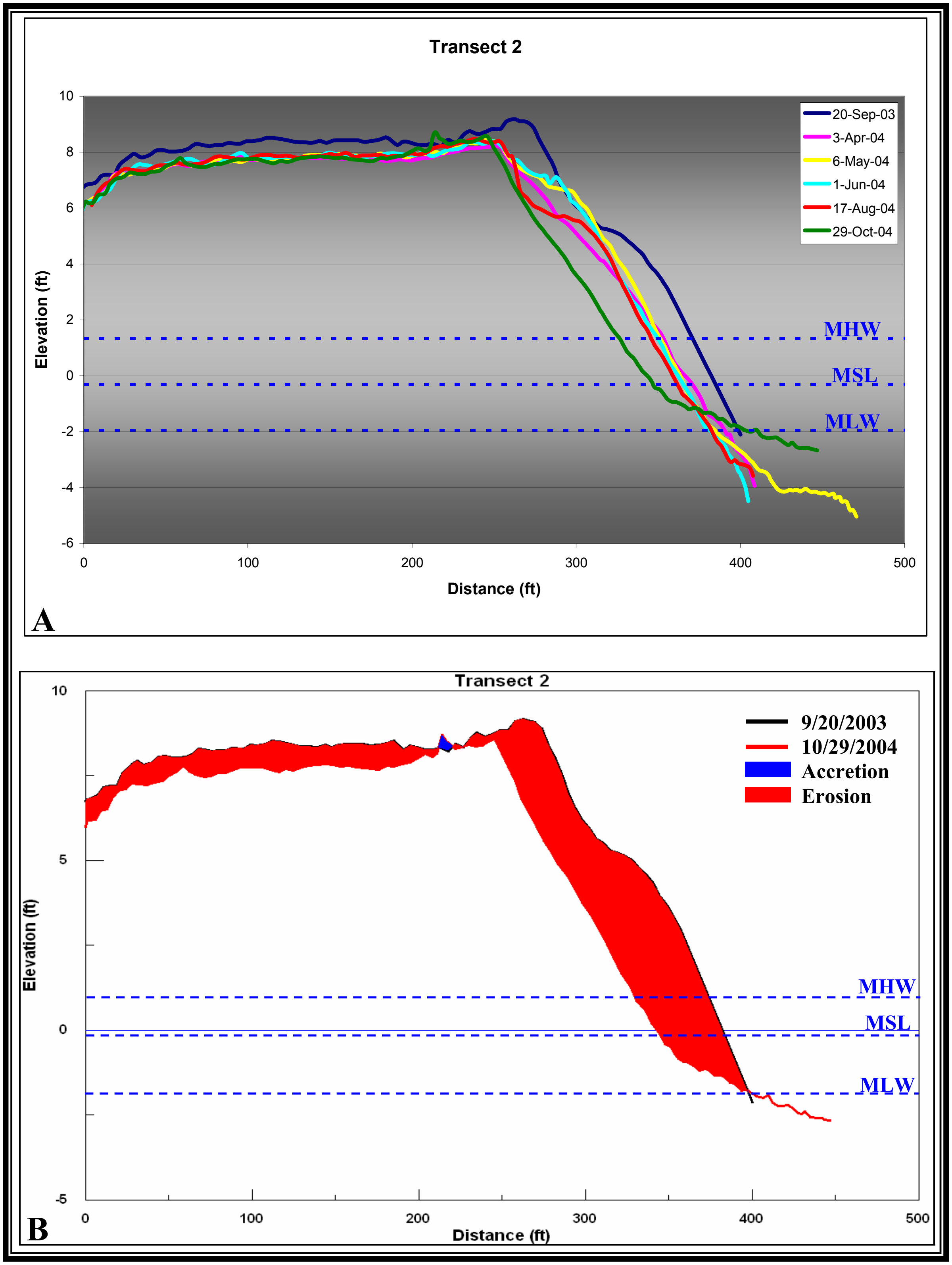

Figure 2: (A) Transect 2 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 2 during the period of September 2003 to October 2004.

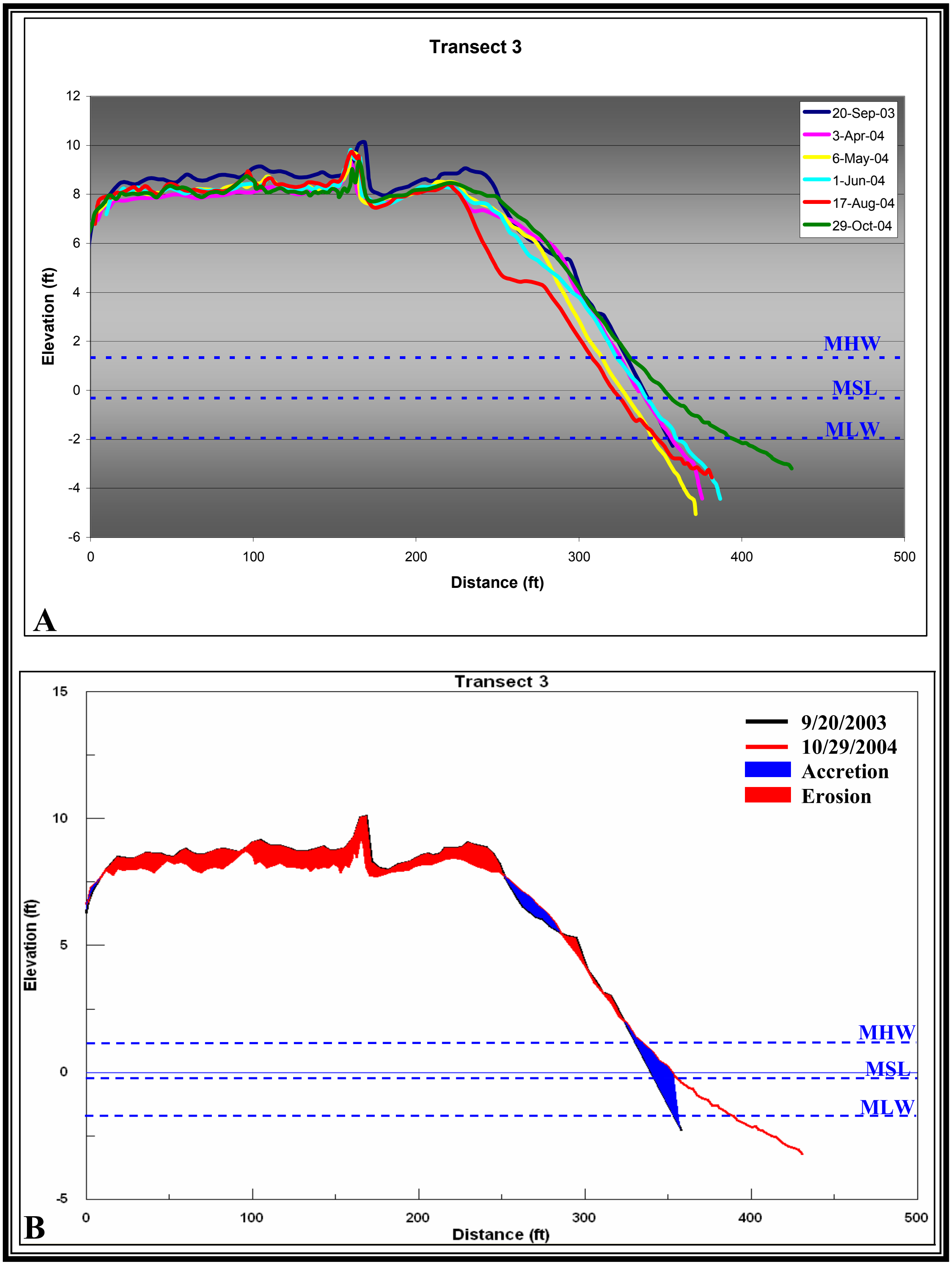

Figure 3: (A) Transect 3 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 3 during the period of September 2003 to October 2004.

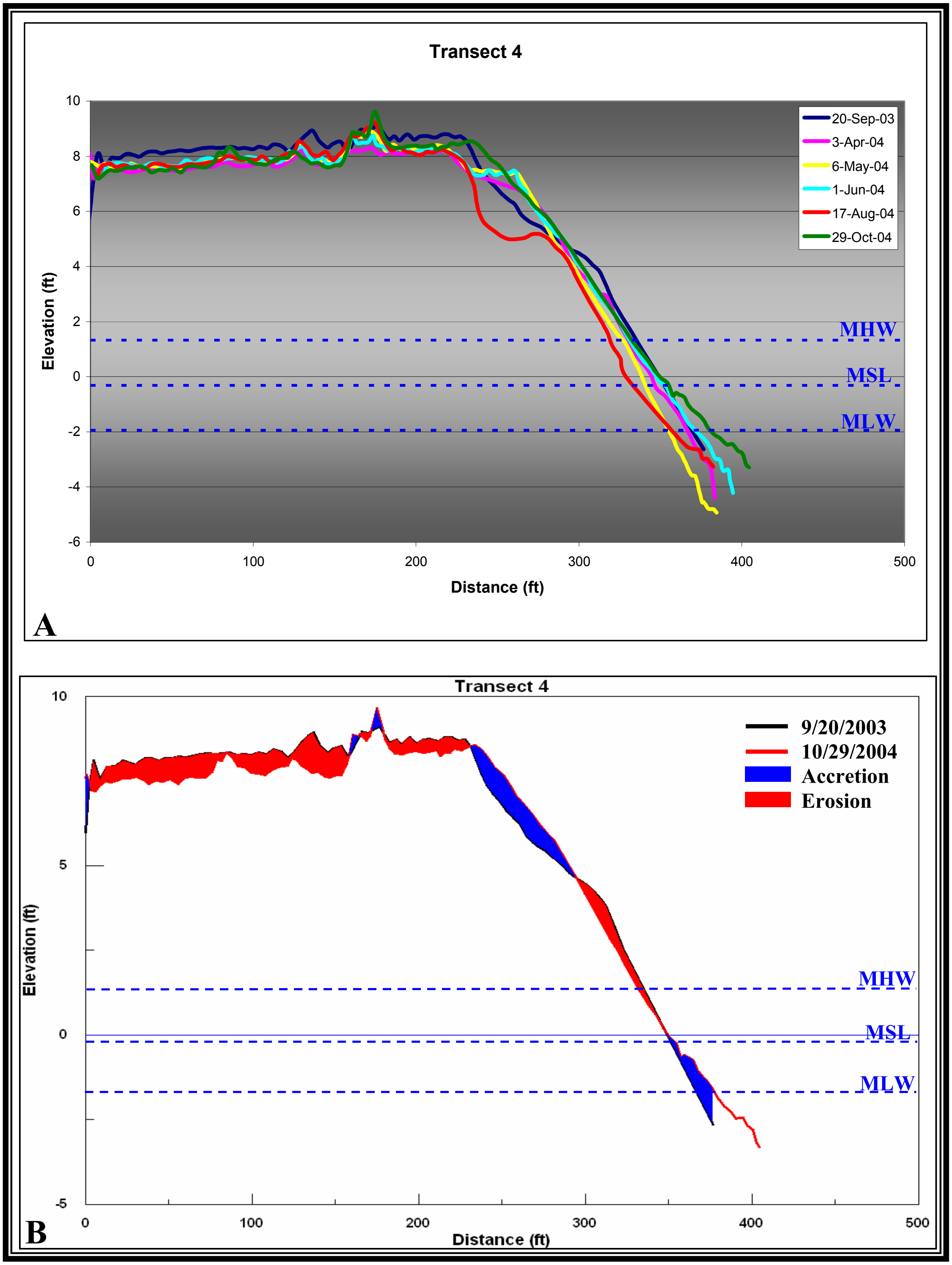

Figure 4: (A) Transect 4 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 4 during the period of September 2003 to October 2004.

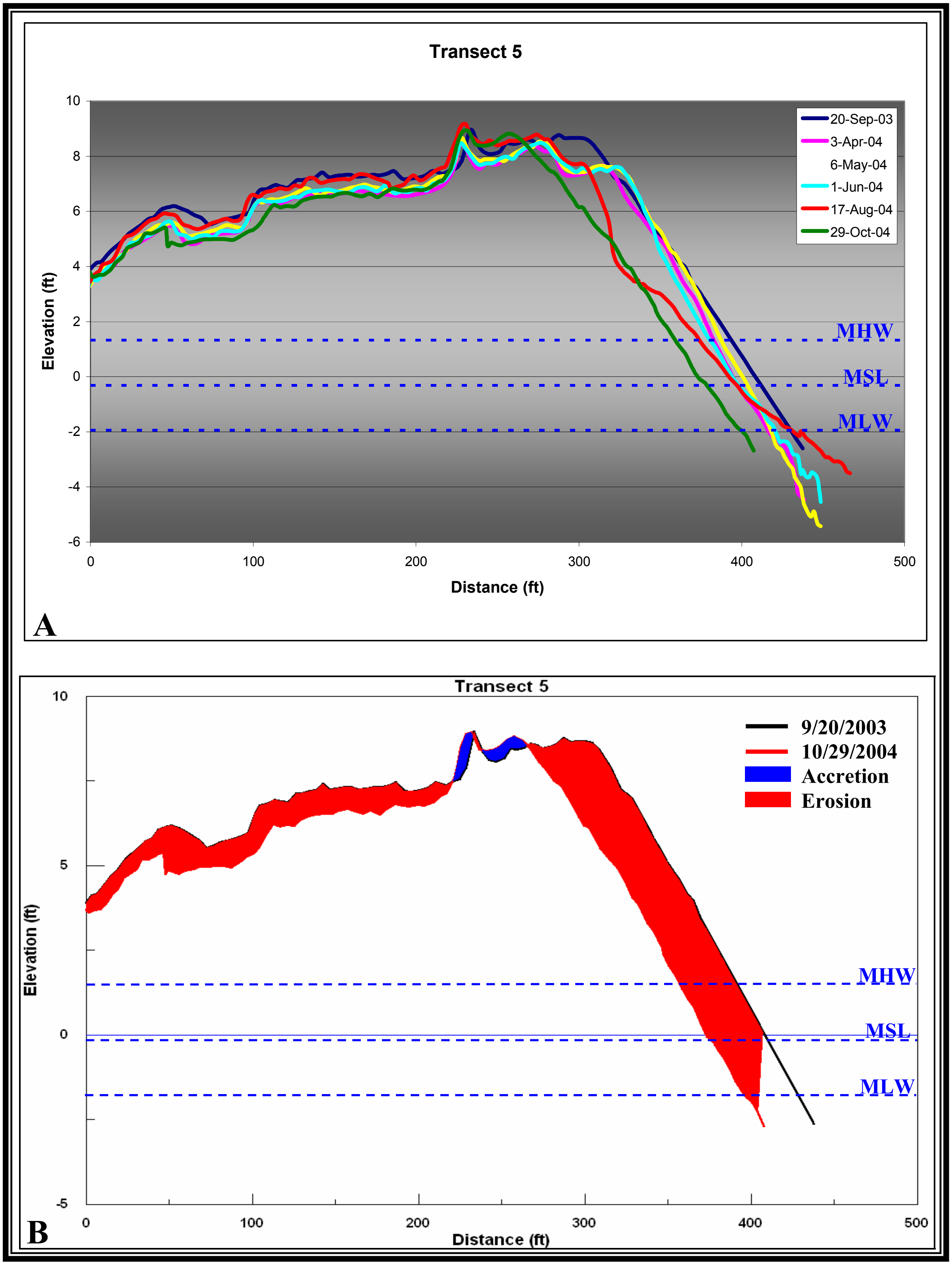

Figure 5: (A) Transect 5 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 5 during the period of September 2003 to October 2004.

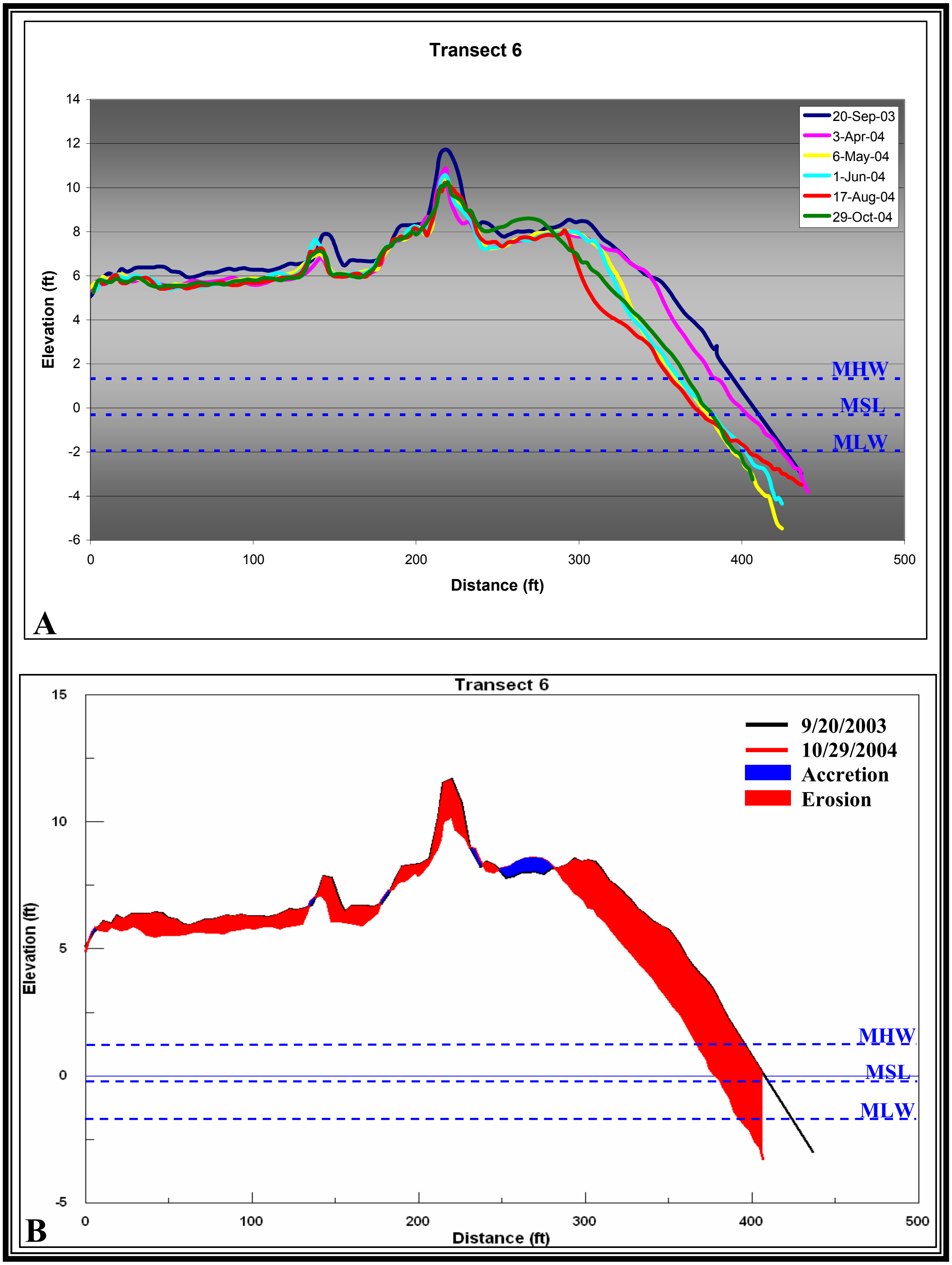

Figure 6: (A) Transect 6 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 6 during the period of September 2003 to October 2004.

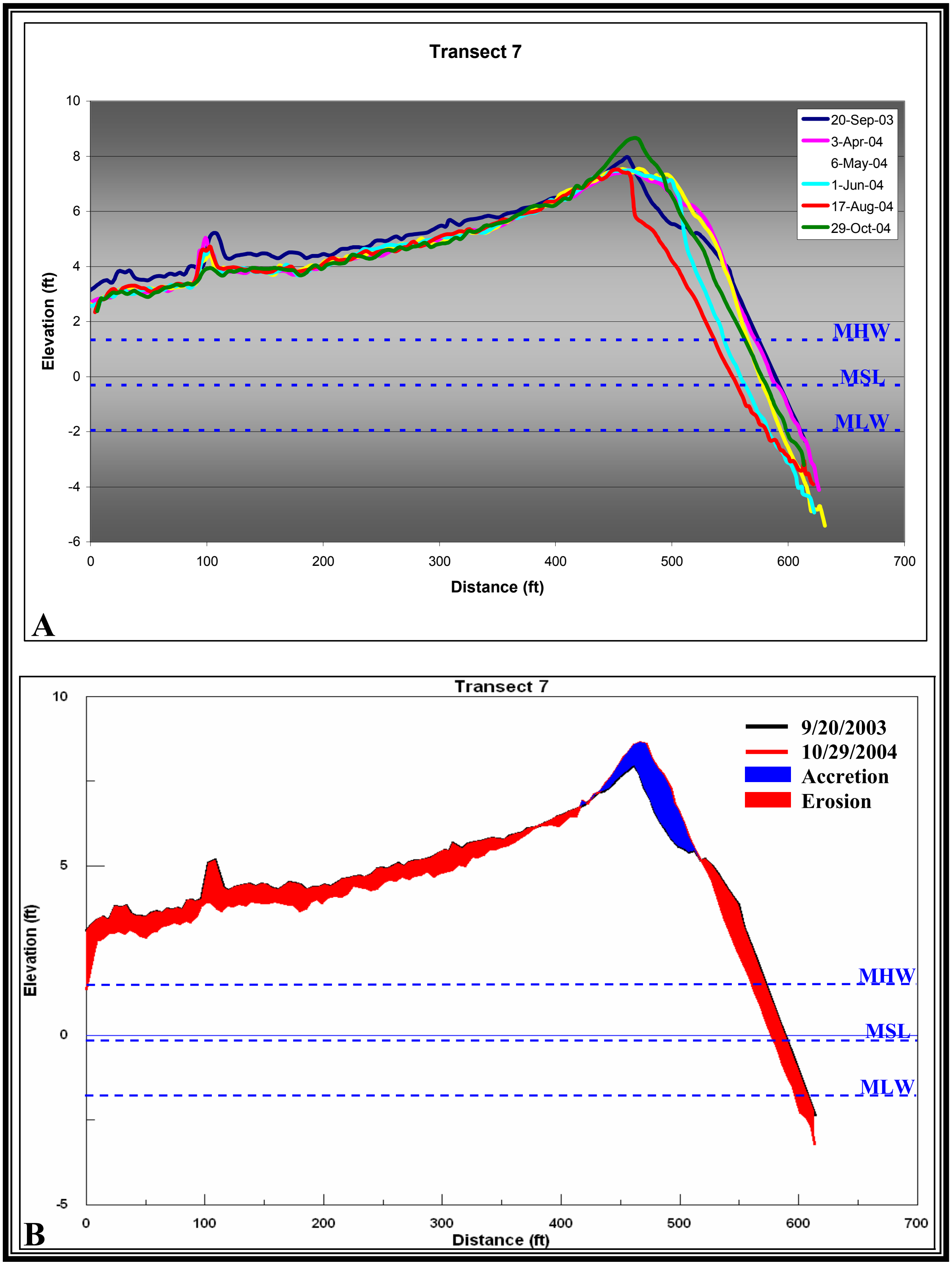

Figure 7: (A) Transect 7 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 7 during the period of September 2003 to October 2004.

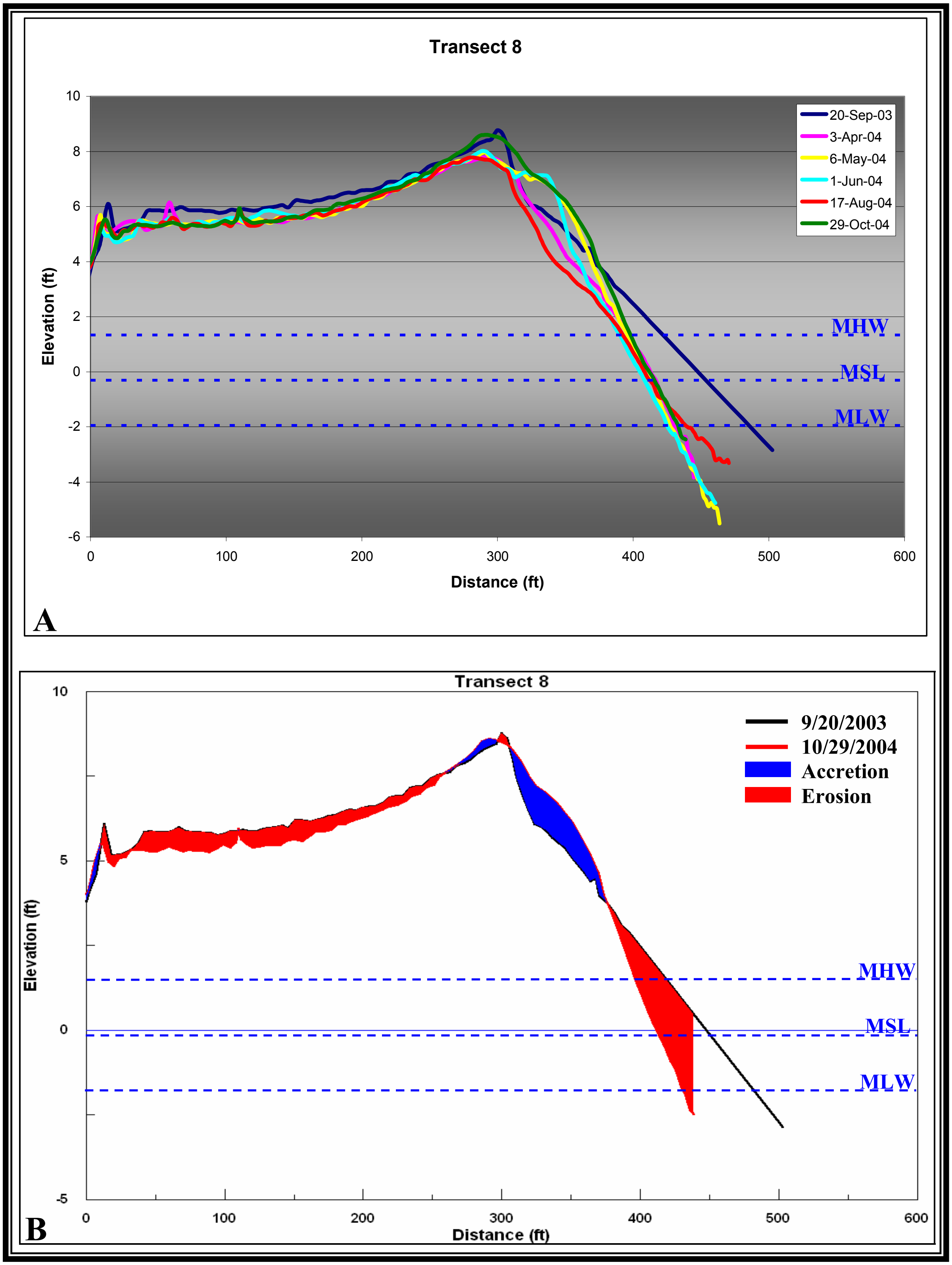

Figure 8: (A) Transect 8 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 8 during the period of September 2003 to October 2004.

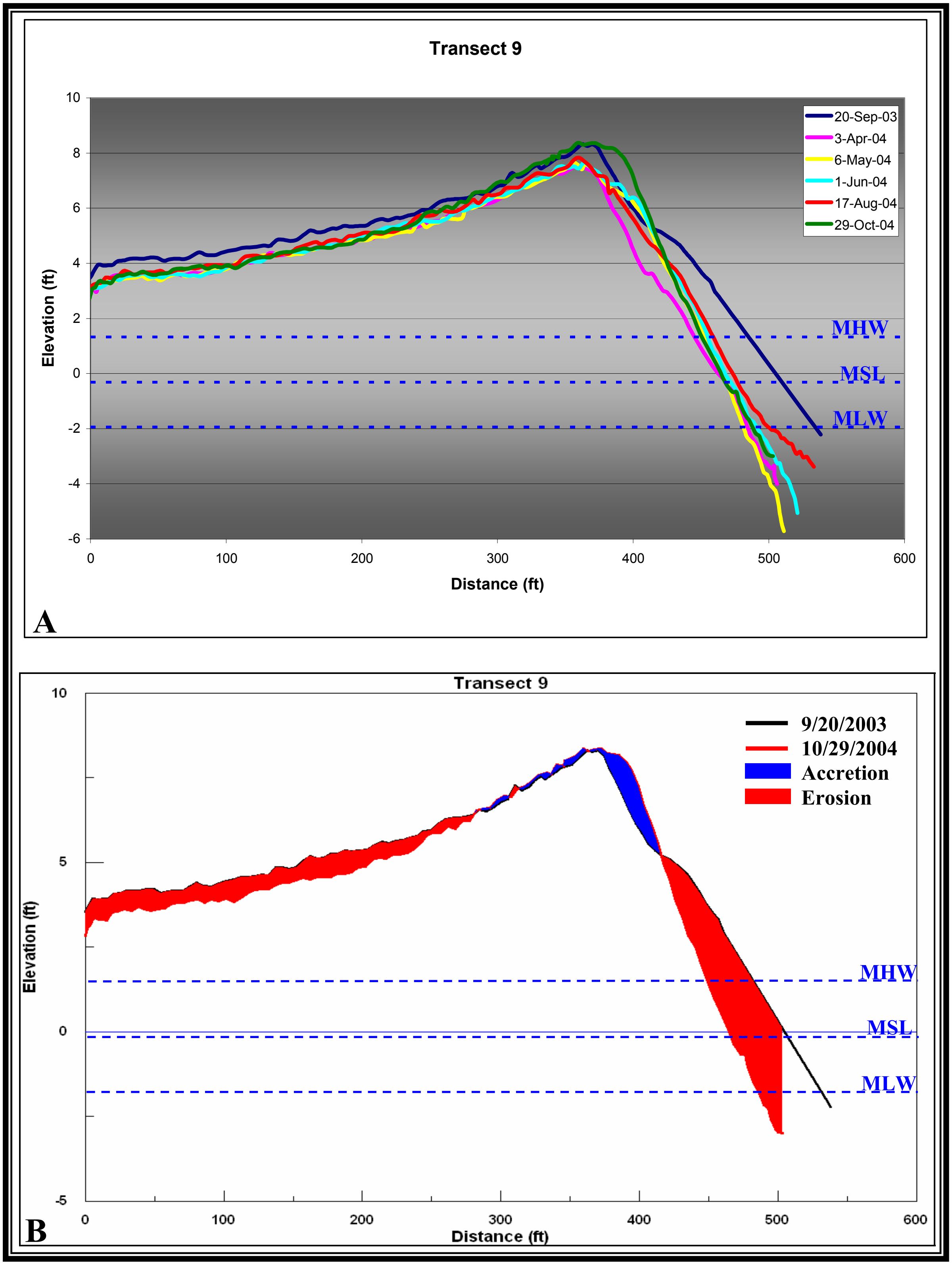

Figure 9: (A) Transect 9 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 9 during the period of September 2003 to October 2004.

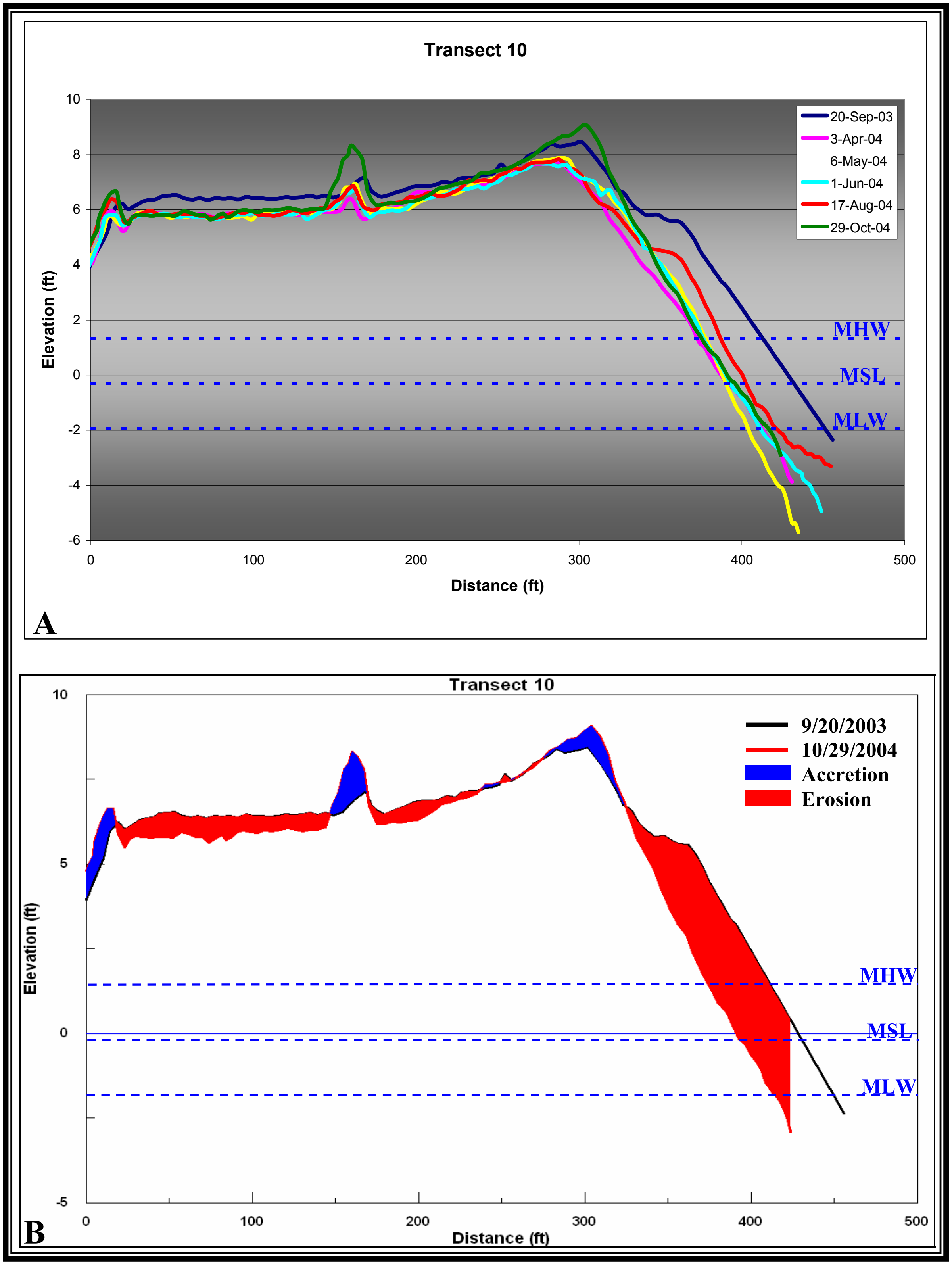

Figure 10: (A) Transect 10 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 10 during the period of September 2003 to October 2004.

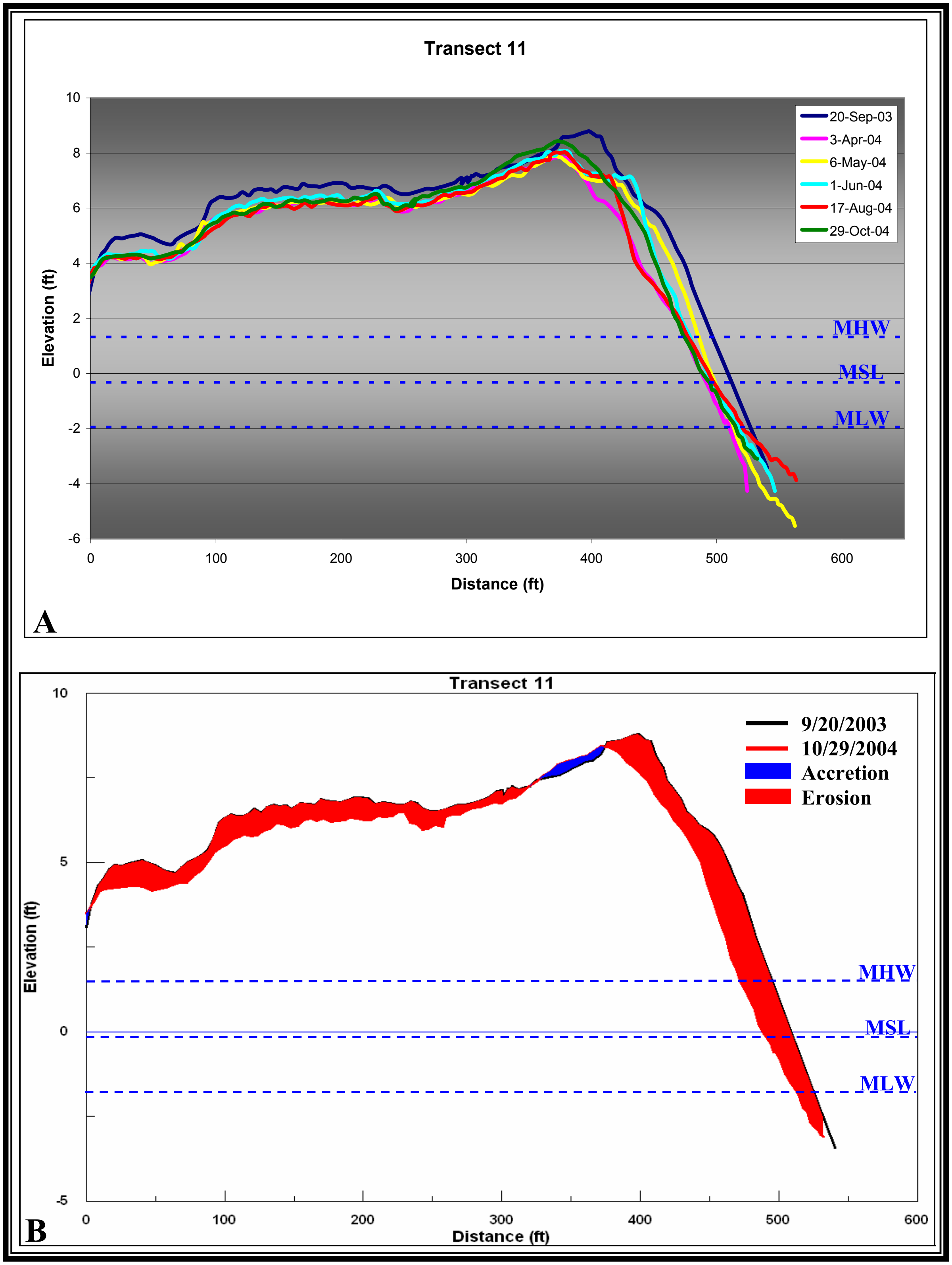

Figure 11: (A) Transect 11 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 11 during the period of September 2003 to October 2004.

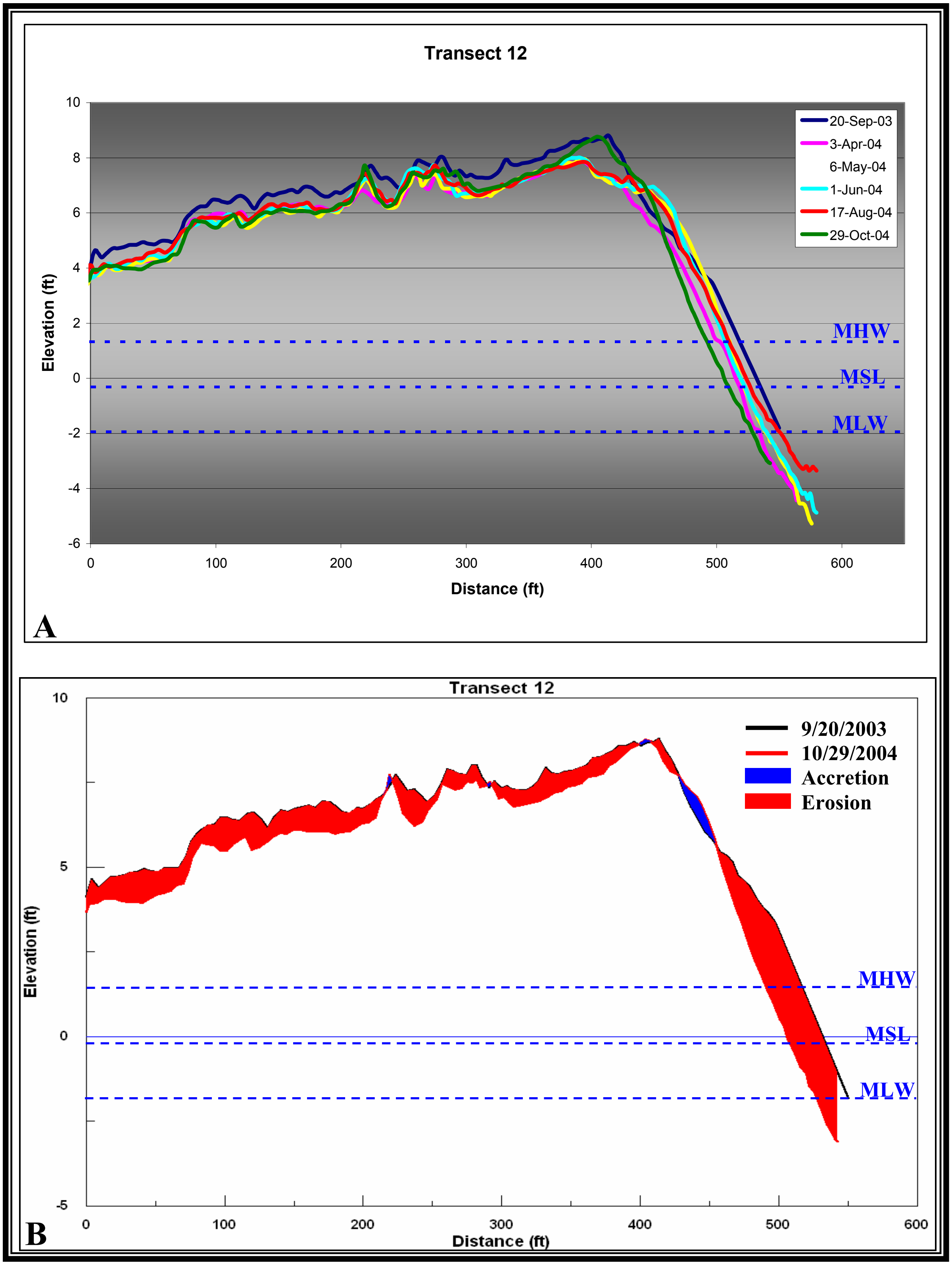

Figure 12: (A) Transect 12 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 12 during the period of September 2003 to October 2004.

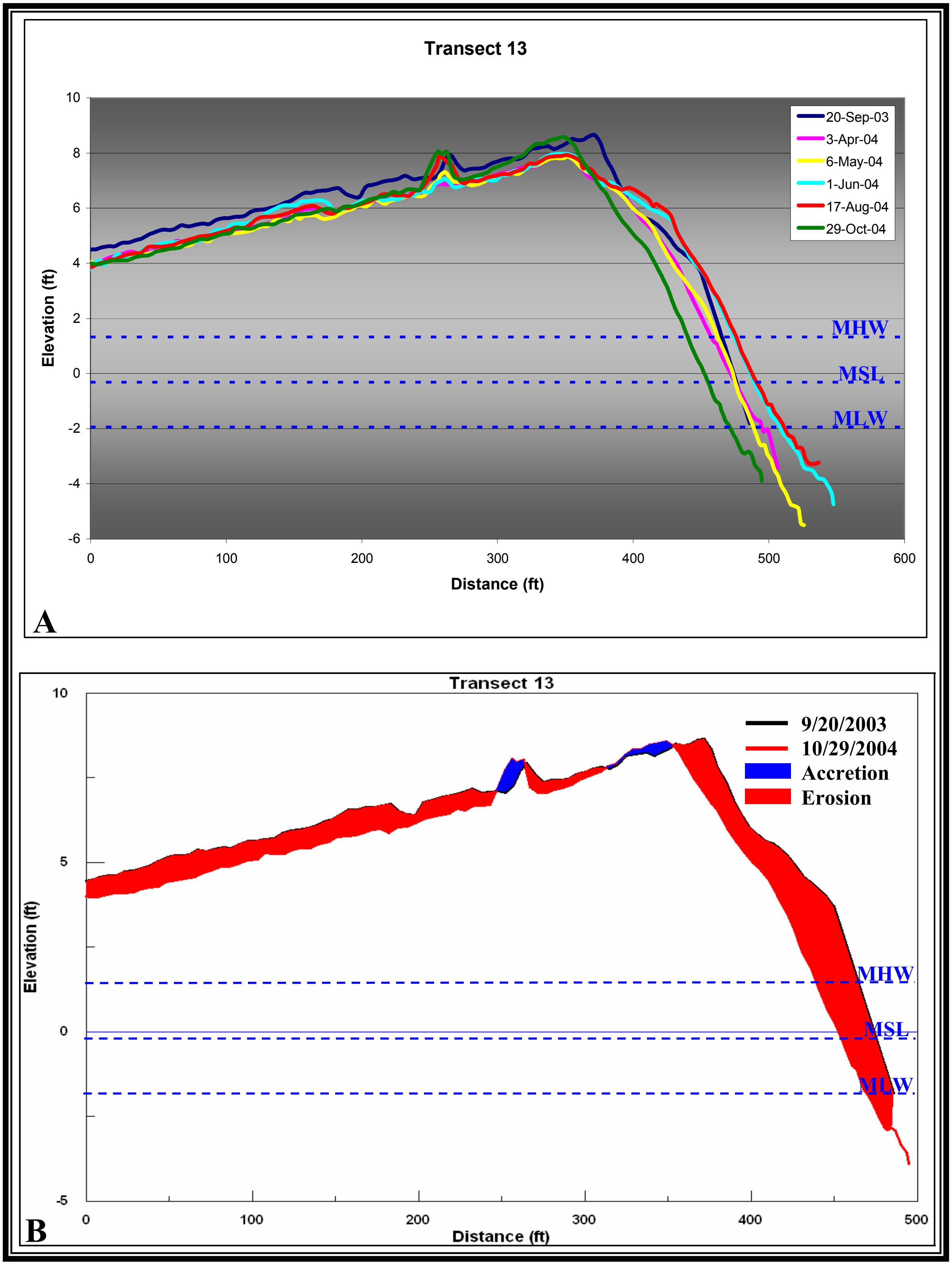

Figure 13: (A) Transect 13 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 13 during the period of September 2003 to October 2004.

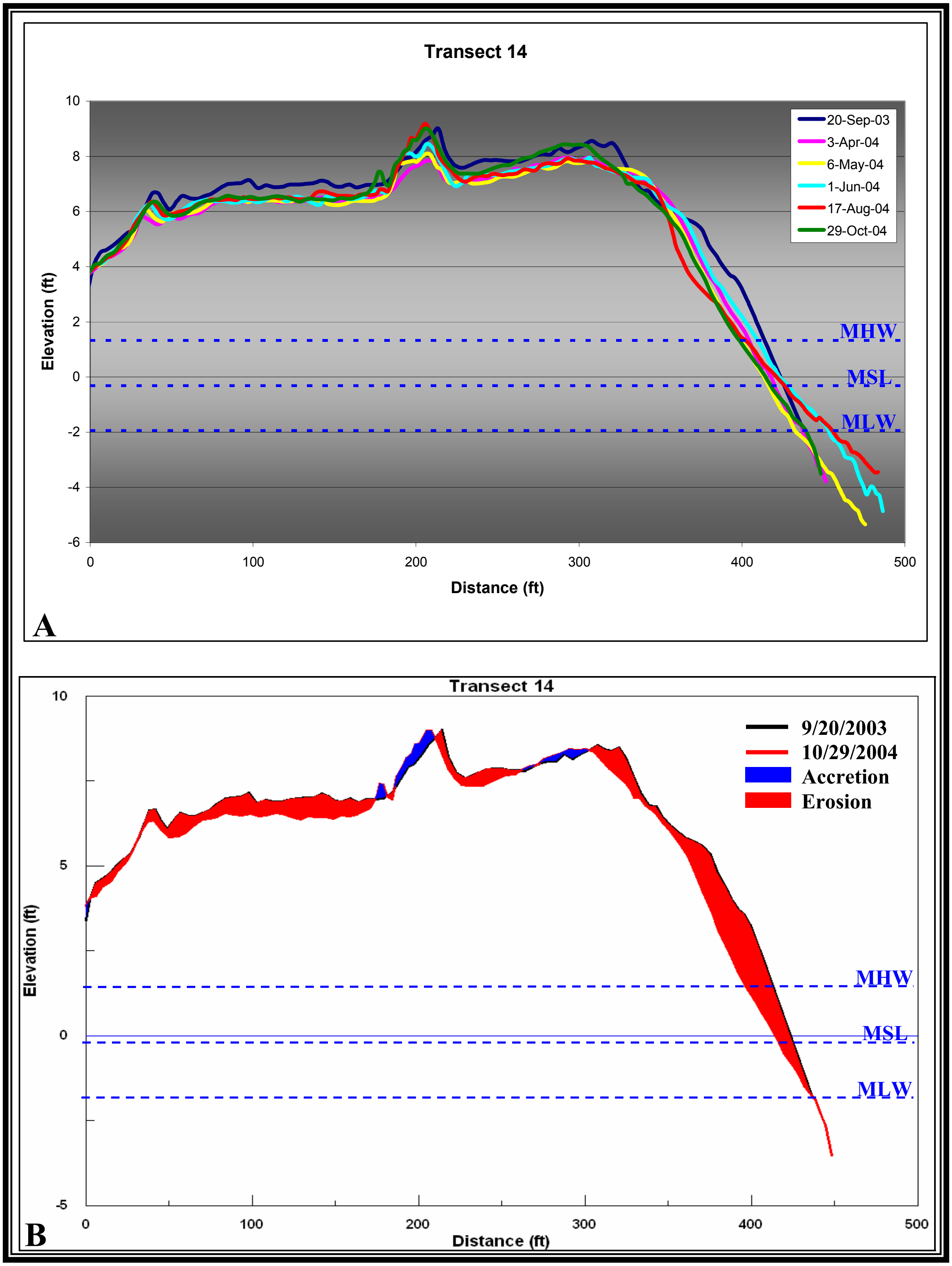

Figure 14: (A) Transect 14 shore-normal profiles surveyed during the period of September 2003 to October 2004. (B) Accretion and erosion along Transect 14 during the period of September 2003 to October 2004.

APPENDIX B: PHOTOGRAPHS OF FOURTEEN TRANSECTS WITHIN HEADLAND INFLUENCED SHORELINE

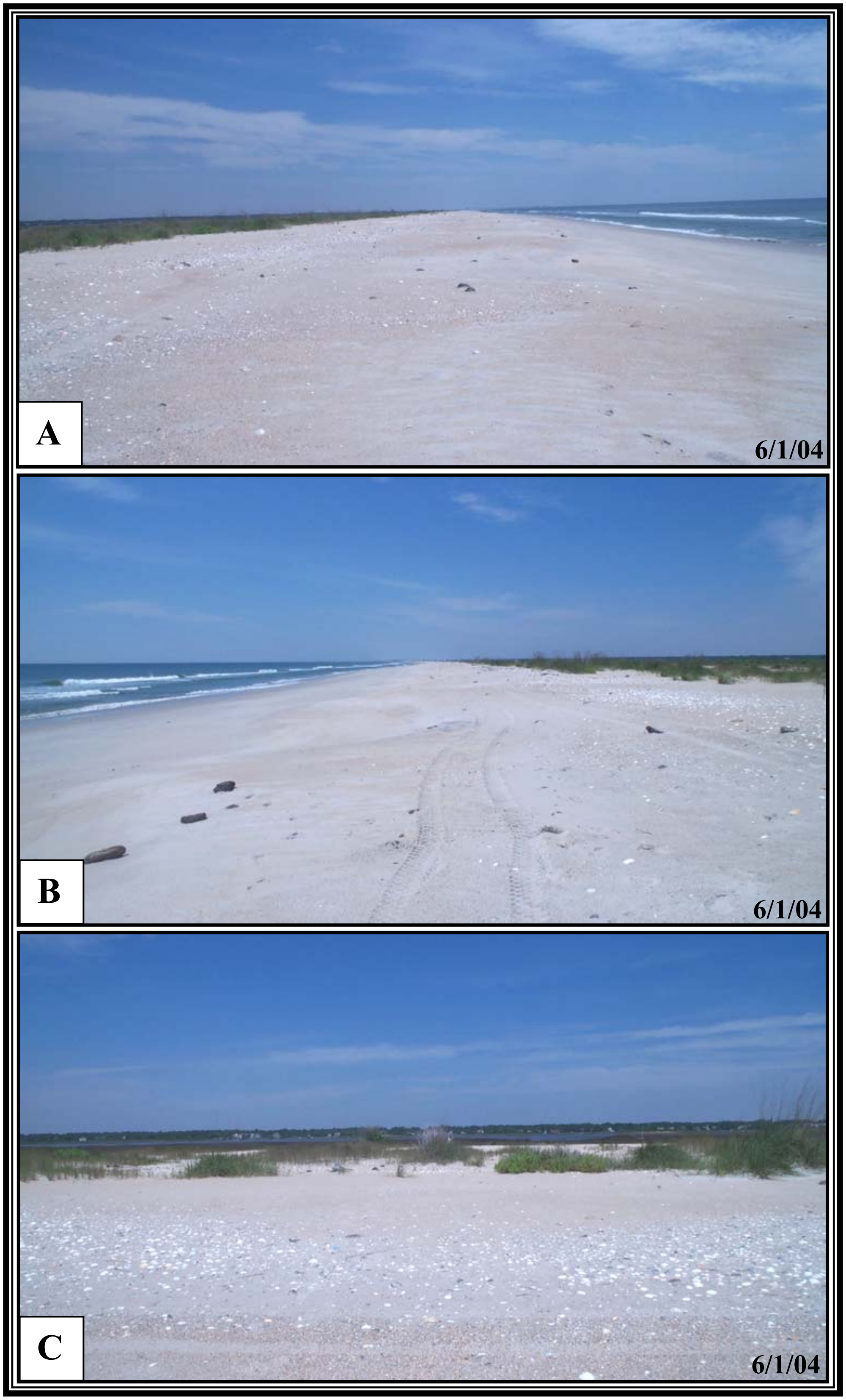

Plate 1. Photographs of Transect 1. (A) North view. (B) South view. (C) West view.

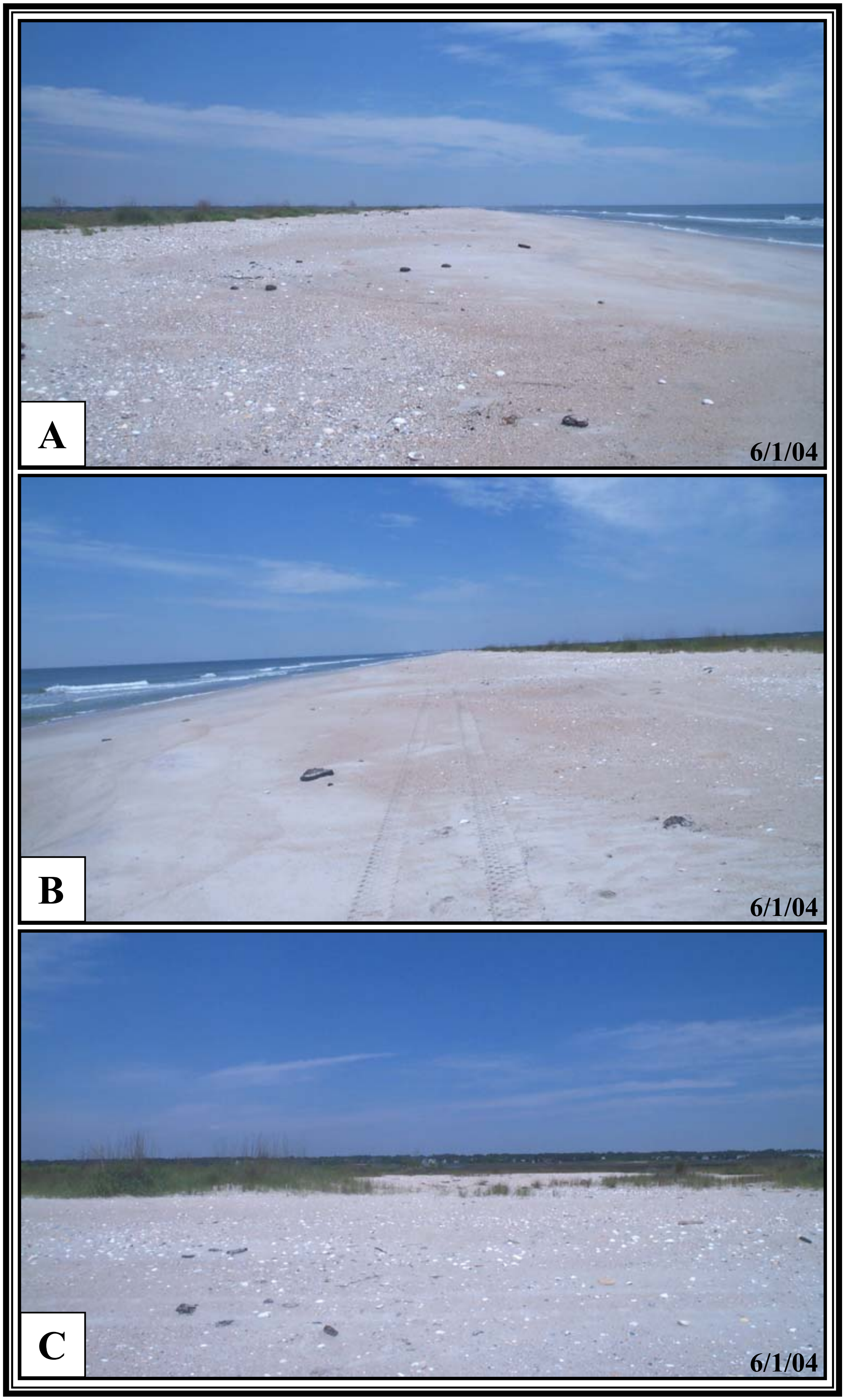

Plate 2. Photographs of Transect 2. (A) North view. (B) South view. (C) West view.

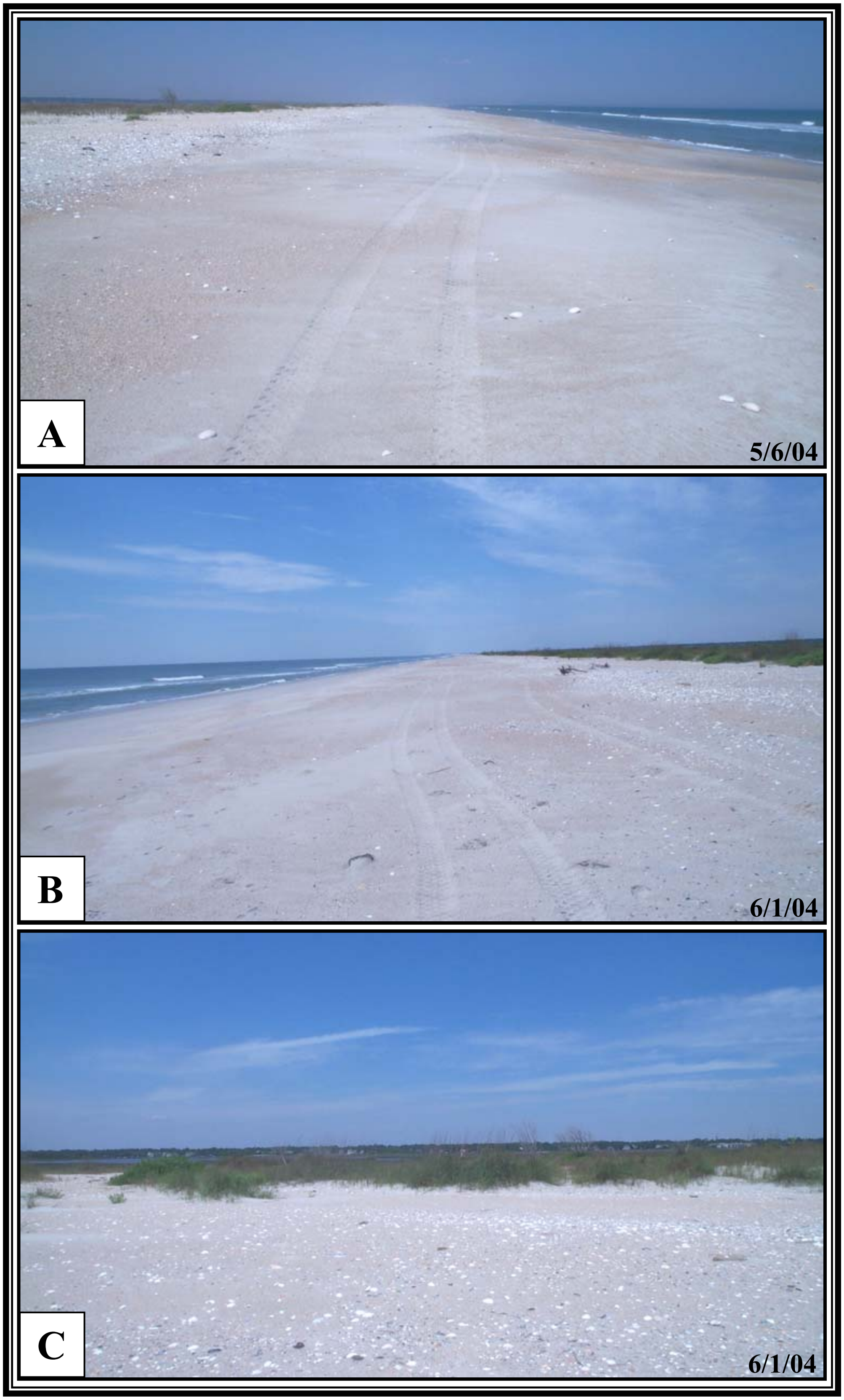

Plate 3. Photographs of Transect 3. (A) North view. (B) South view. (C) West view.

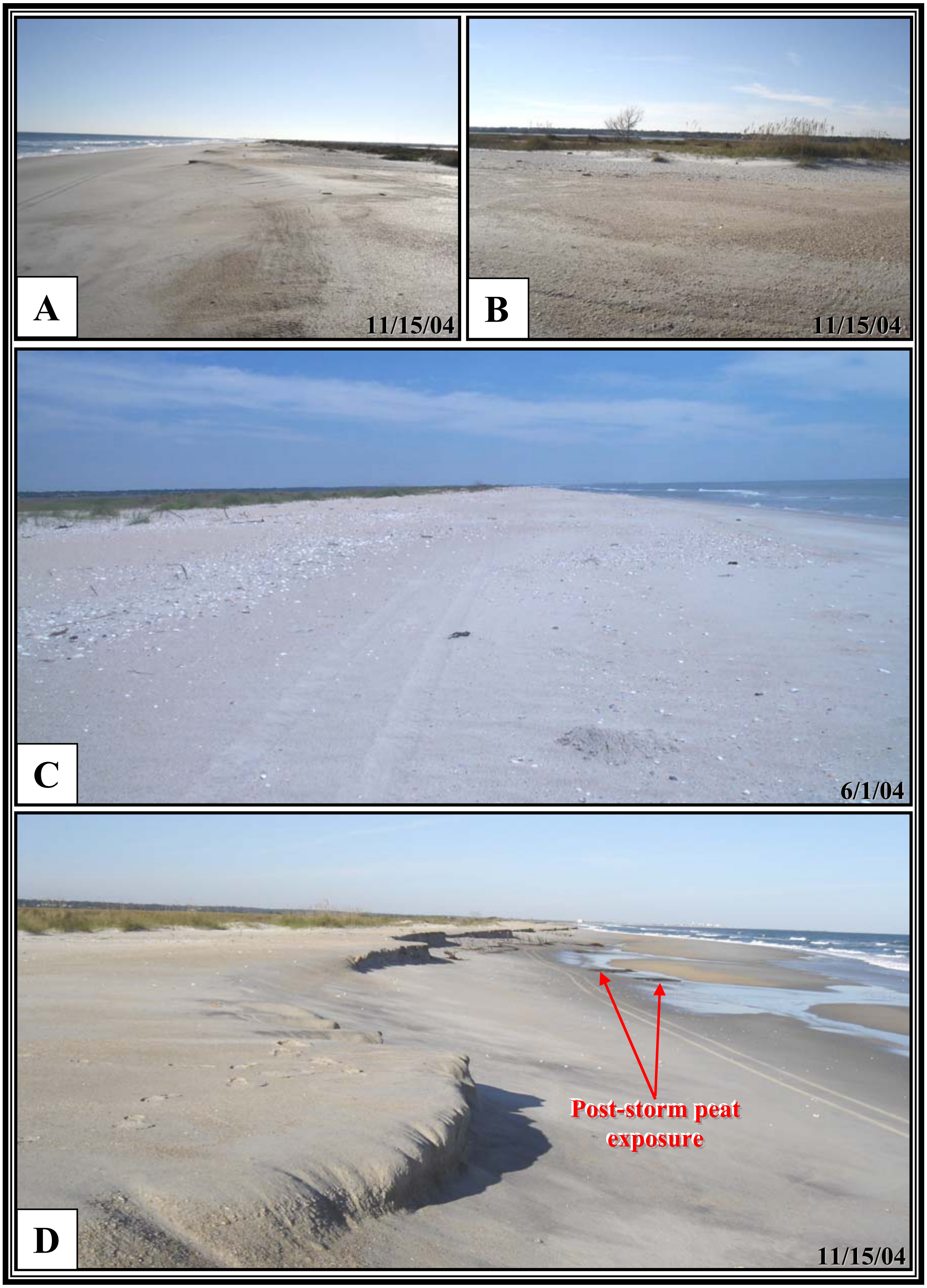

Plate 4. Photographs of Transect 4. (A) South view. (B) West view. (C) North view prior to winter storm. (D) North view after winter storm.

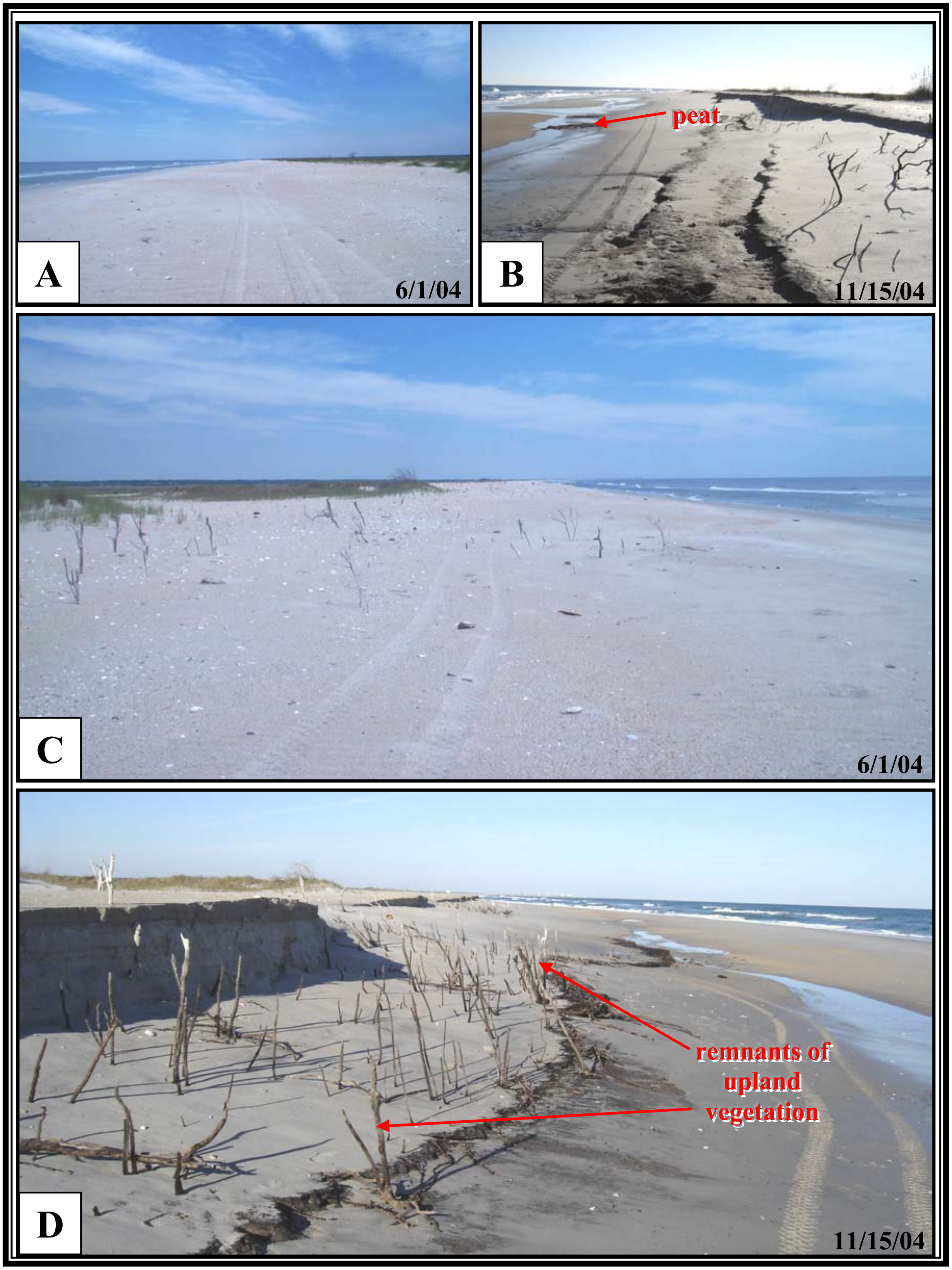

Plate 5. Photographs of Transect 5. (A) South view prior to winter storm. (B) South view after winter storm. (C) North view prior to winter storm. (D) North view after winter storm.

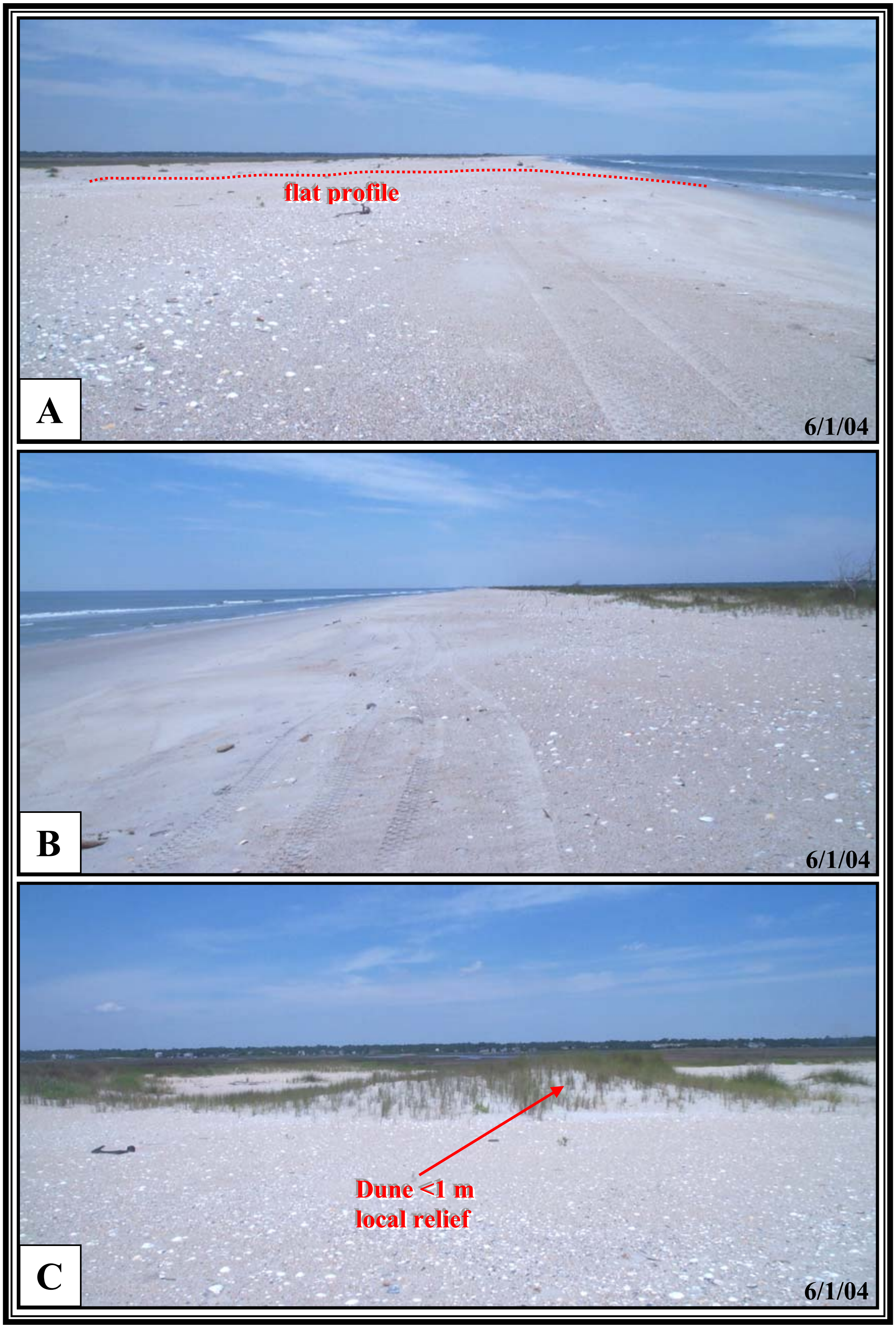

Plate 6. Photographs of Transect 6 (see Figure 9). (A) North view. (B) South view. (C) West view.

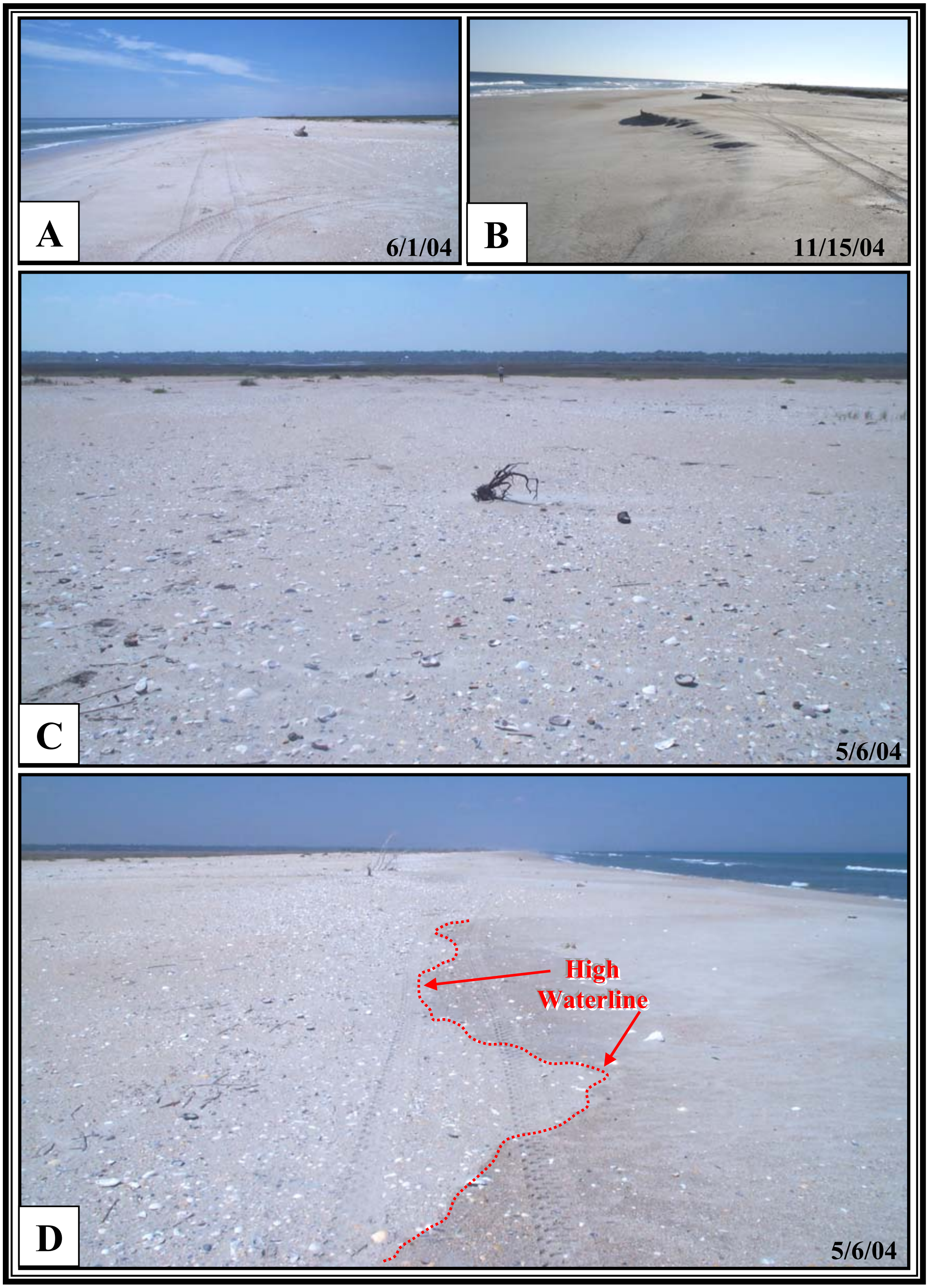

Plate 7. Photographs of Transect 7 (see Figure 9). (A) South view. (B) South view after winter storm. (C) West view of washover terrace. Note the absence of dunes in this area. (D) North view. Position of high waterline indicates that waves can easily overtop the island during fair-weather conditions.

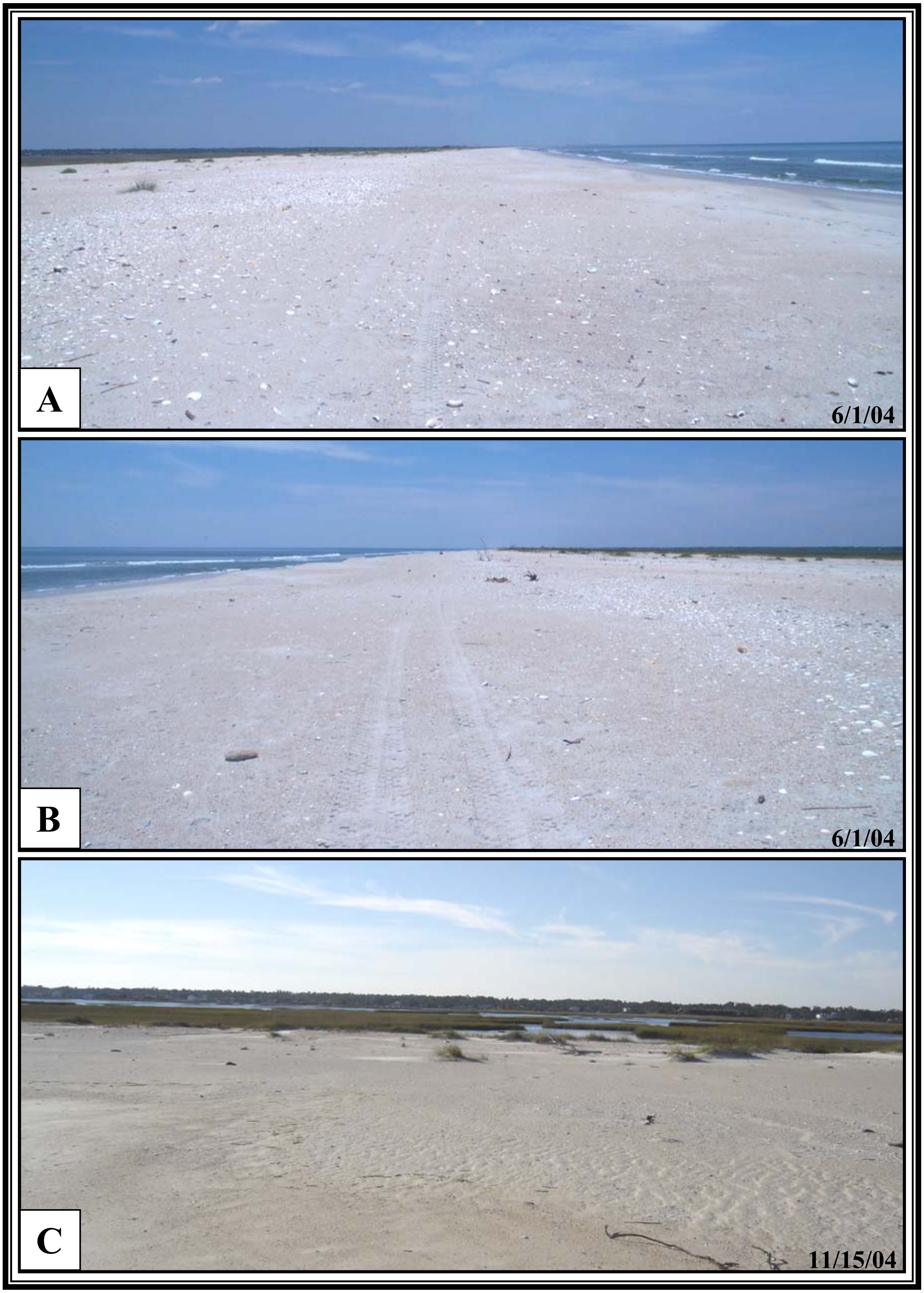

Plate 8. Photographs of Transect 8 (see Figure 9). (A) North view. (B) South view. (C) West view.

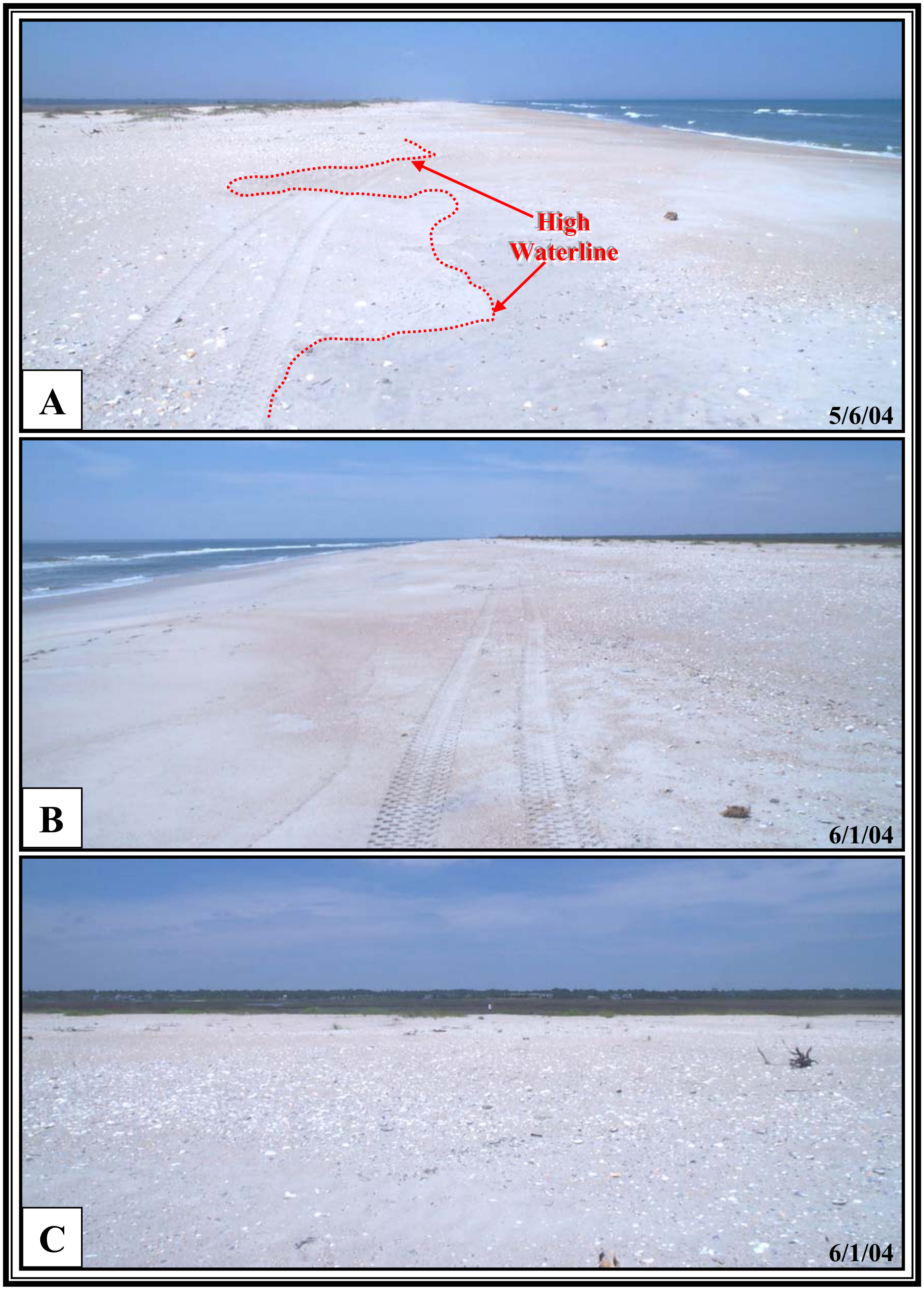

Plate 9. Photographs of Transect 9 (see Figure 9). (A) North view. Position of high waterline indicates that waves can easily overtop the island during fair-weather conditions. (B) South view. (C) West view of washover terrace.

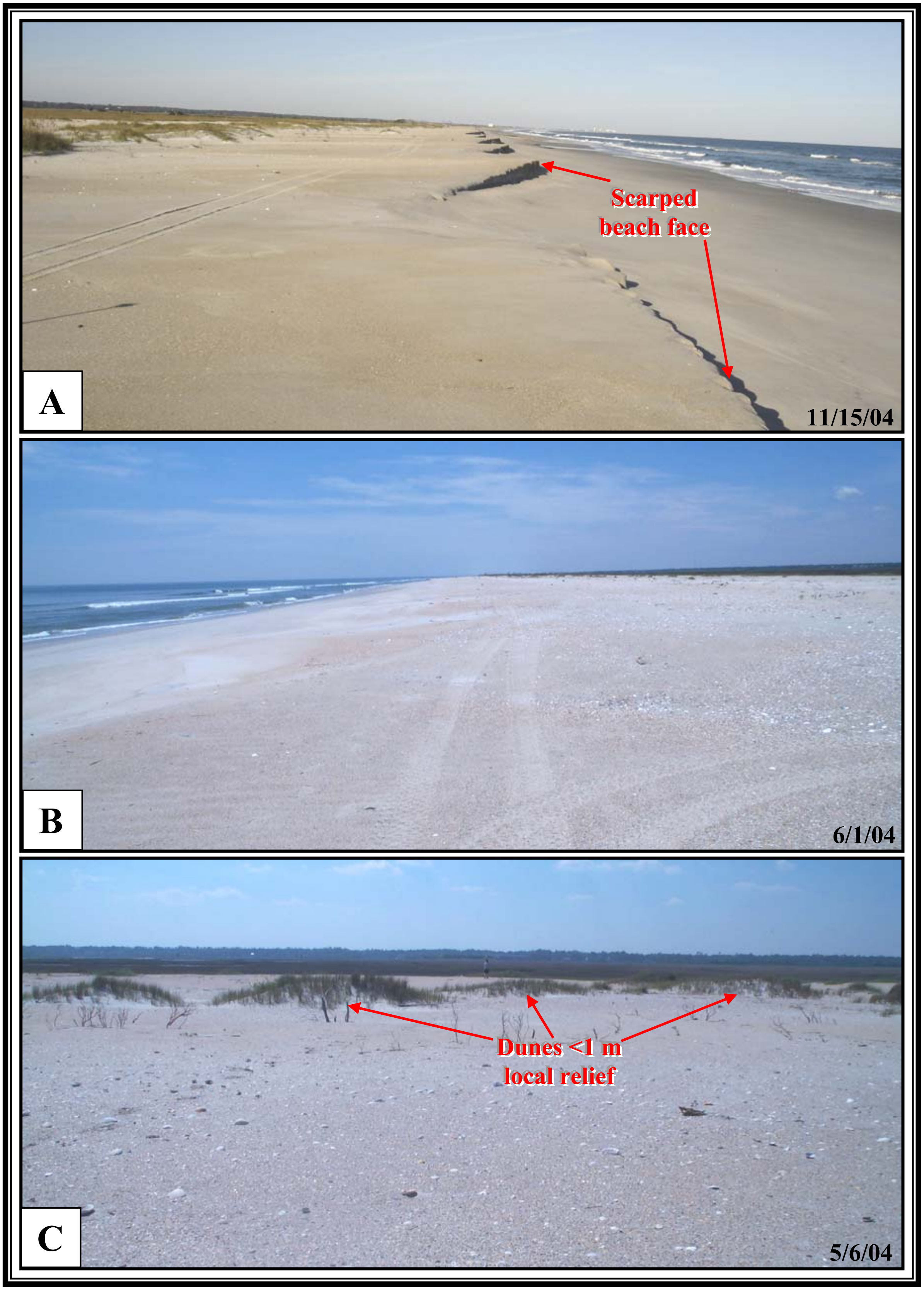

Plate 10. Photographs of Transect 10 (see Figure 9). (A) North view after winter storm. (B) South view. (C) West view of washover terrace with sporadic dune coverage.

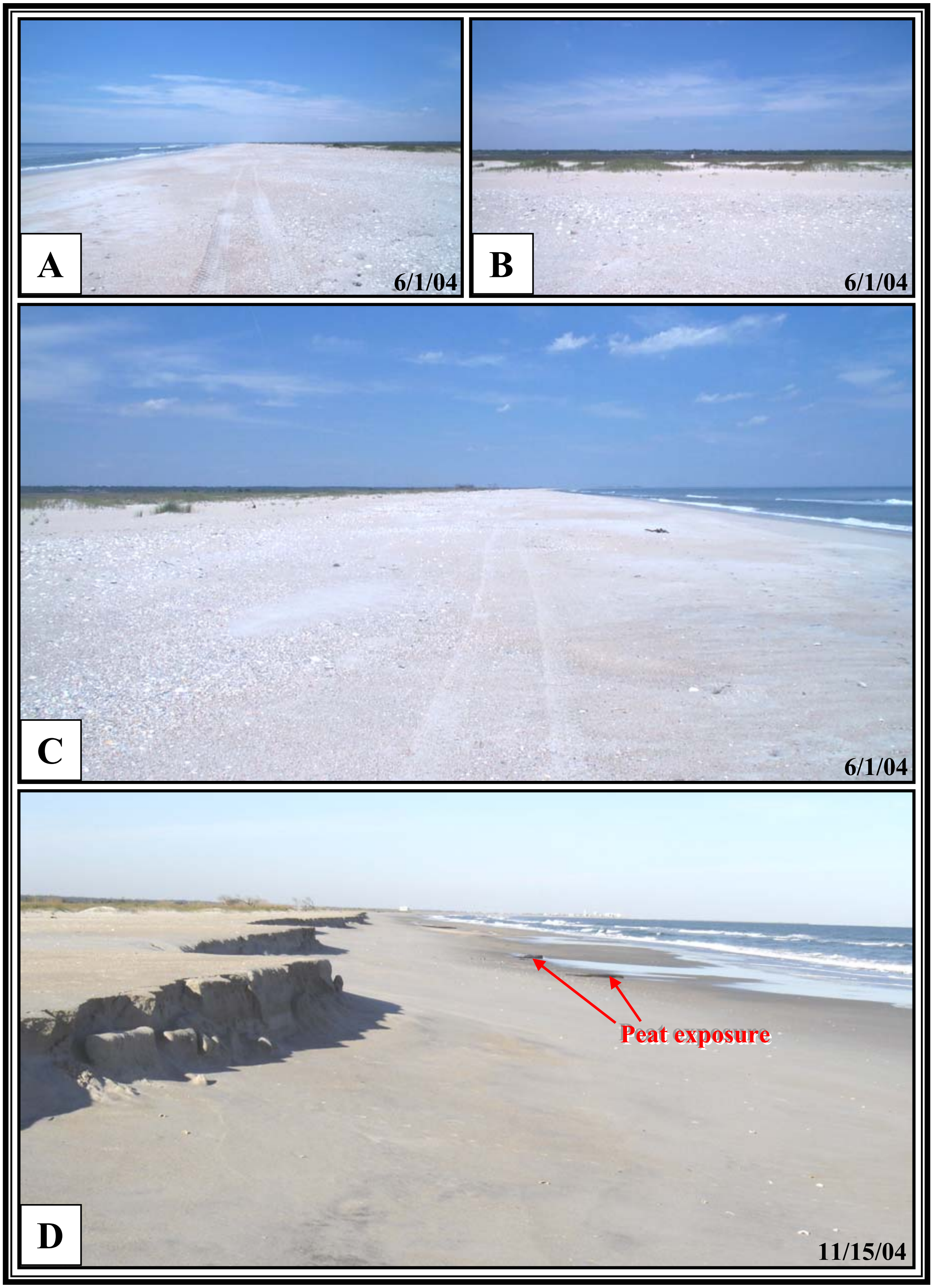

Plate 11. Photographs of Transect 11 (see Figure 9). (A) South view. (B) West view. (C) North view. (D) North view after winter storm.

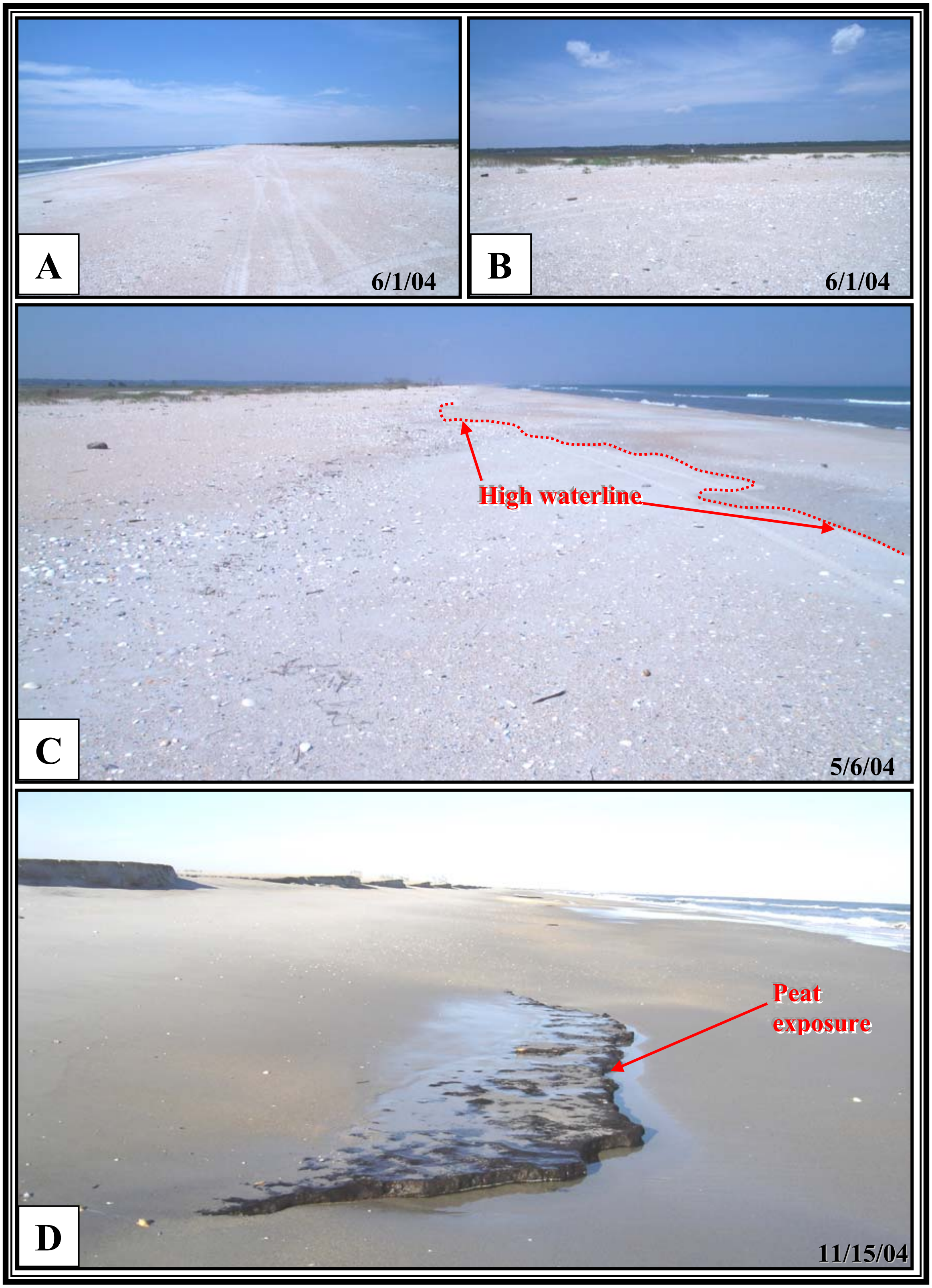

Plate 12. Photographs of Transect 12 (see Figure 9). (A) South view. (B) West view. (C) North view. (D) North view after winter storm. Peat exposure is ~1 m in width and ~5 m in length.

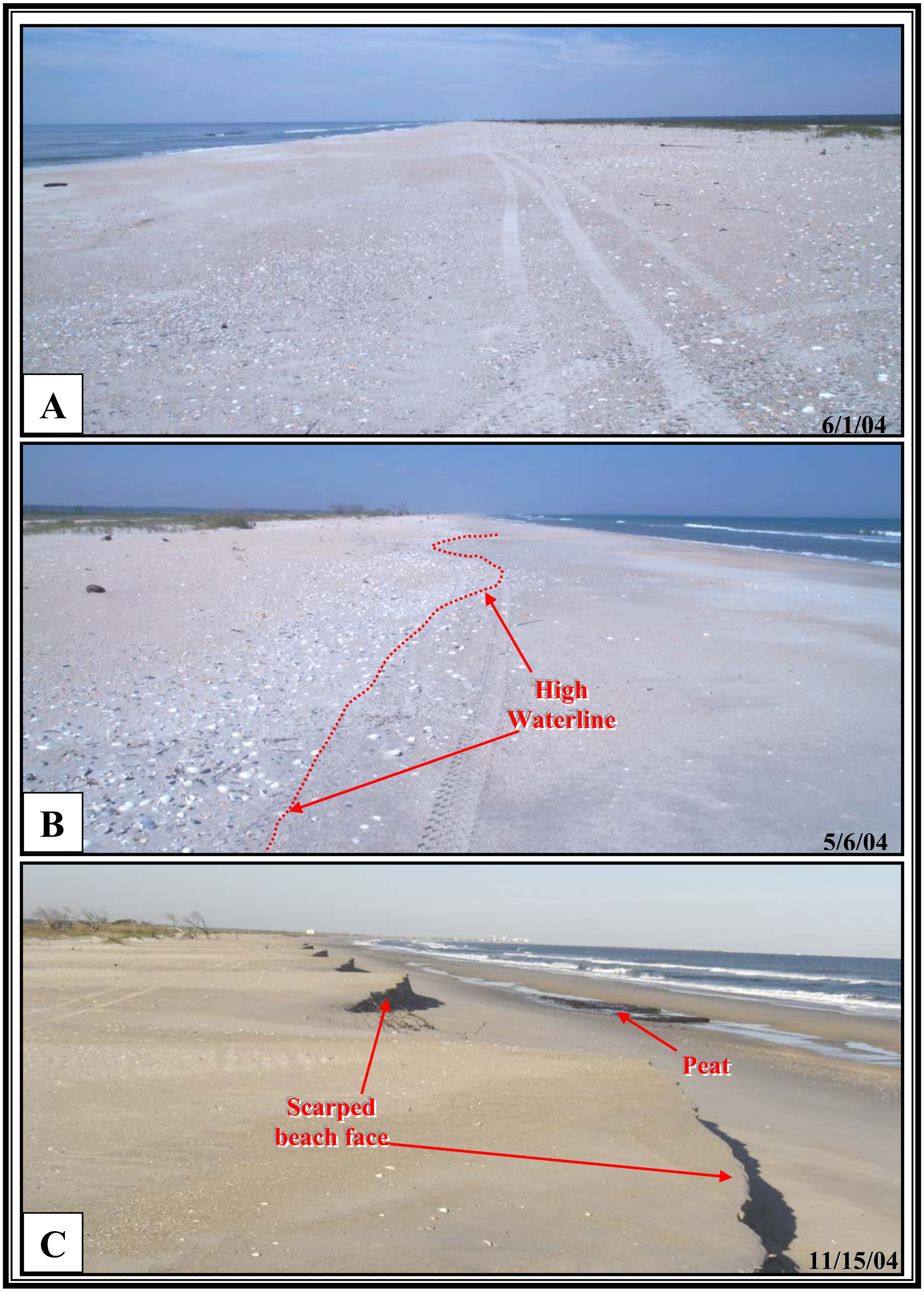

Plate 13. Photographs of Transect 13 (see Figure 9). (A) South view. (B) North view. Position of high water line indicates waves can easily overtop the island. (C) North view after winter storm.

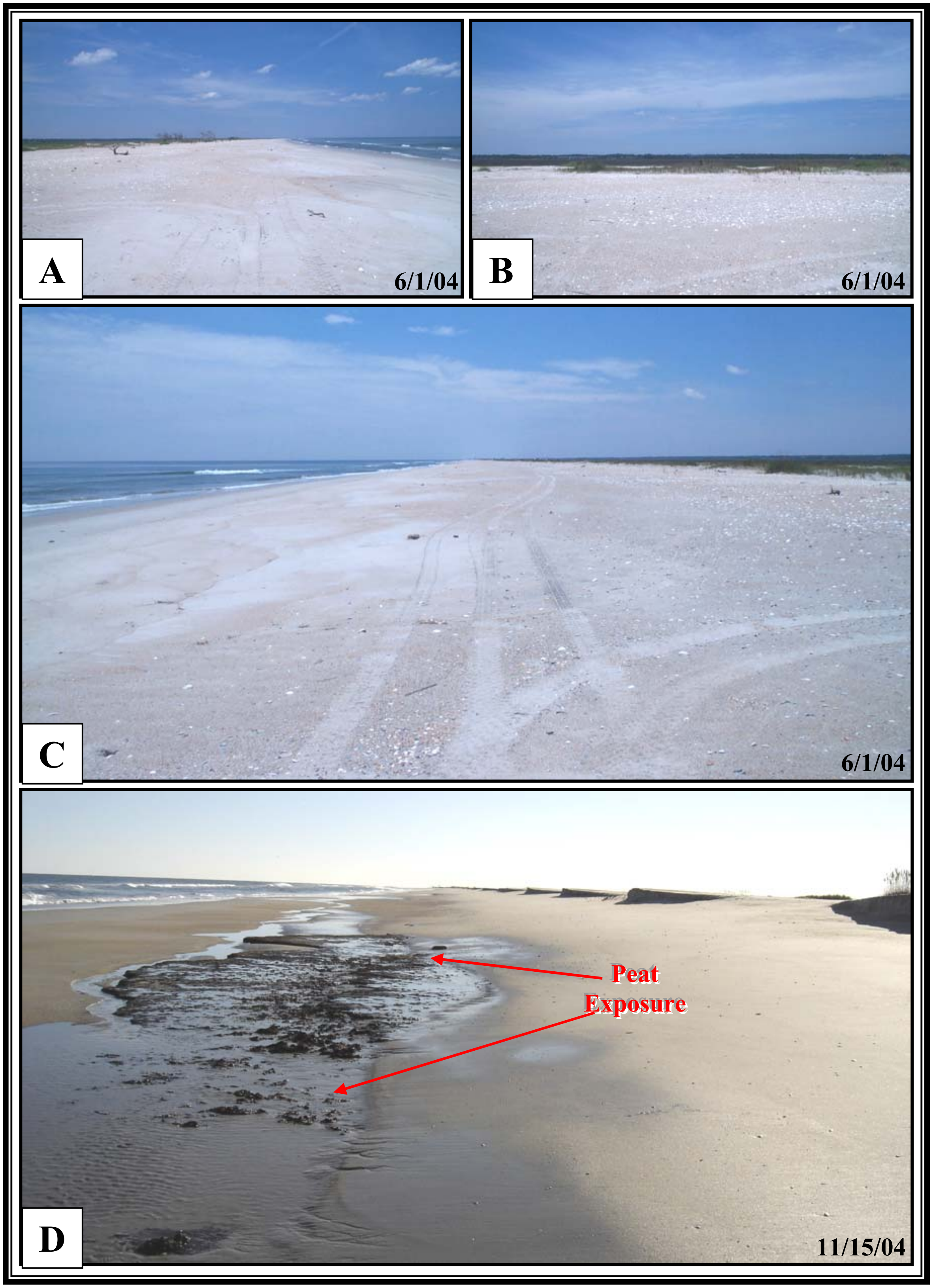

Plate 14. Photograph of Transect 14 (see Figure 9). (A) North view. (B) West view. (C) South view. (D) South view after winter storm.

APPENDIX C: ESTUARINE CORE DESCRIPTIONS

Appendix C. Description of vibracores from Masonboro Island estuary.

Core-ID	Length		Description	Comments	Elevation
MBDD01	280 cm	0-39 cm	Light tan to light gray fine to medium sand.	Scattered pieces of *Gemma Gemma.*	-0.5 m
		39-88 cm	Dark gray muddy fine sand.	2 cm articulated shell at 50 cm depth and mud snails (*Nassarius* sp.) at 70 cm.	
		88-116 cm	Dark gray muddy fine sand.	Thick layer of *Gemma Gemma* between 98-102 cm. Large cluster of articulated shells () from102-116 cm.	
		116-173 cm	Light to dark gray fine to very fine sand.	Some disarticulated shells (*Mercenaria* sp. and *Tagelus*) between 166-172 cm.	
		173-217 cm	Dark gray sandy mud with some shell fragments.		
		217-280 cm	Light gray to bluish gray muddy sand.	Top of Pleistocene	
MBDD02	222 cm	0-17 cm	Dark brown muddy fine sand to medium sand.	Modern estuarine fill.	-0.38 m
		17-75 cm	Light brown to dark brown fine sand grading into light gray fine sand.	Relatively clean sand with some shell fragments.	
		75-137 cm	Light gray medium sand with abundant shell fragments.	Channel deposit or inlet fill.	
		137-182 cm	Dark brown muddy fine sand with minor amounts of shell fragments.		
		182-222 cm	Light gray to light brown mud.	Top of Pleistocene	

Appendix C. (Continued).

Core-ID	Length		Description	Comments	Elevation
MBDD03	360 cm	0-5 cm	Very dark gray sandy mud.	Modern estuarine fill.	-0.38 m
		5-24 cm	Dark gray to dark brown muddy fine sand.		
		24-37 cm	Light gray fine to medium sand with abundant shell hash.	Channel deposit or inlet fill.	
		37-130 cm	Light gray fine sand with moderate amounts of shell fragments.	Cluster of articulated shells (*Mercenaria* sp.) between 60-67 cm and 104-116 cm.	
		130-360 cm	Light greenish gray muddy very fine sand. Grades into very clean very fine sand.	All Pleistocene sediment. Color grades from initial light greenish gray to greenish-yellowish orange at 320 cm and then to dark gray at 358 cm.	
MBDD04	157 cm	0-39 cm	Dark brown sandy mud grading into light gray to light tan muddy sand.	Modern estuarine fill.	-0.25 m
		39-125 cm	Medium to coarse sand with abundant shell hash.	Channel deposit or inlet fill.	
		125-157 cm	Light bluish gray mud with some yellowish orange oxidized muddy silt.	Top of Pleistocene.	

Appendix C. (Continued).

Core-ID	Length		Description	Comments	Elevation
MBDD05	454 cm	0-13 cm	Dark gray muddy fine sand.	Modern estuarine fill.	-0.11 m
		13-79 cm	Light gray relatively clean very fine sand.	Minor amounts of shell hash contains *Gemma Gemma.*	
		79-155 cm	Dark gray muddy very fine sand. Grades into underlying unit.	Minor shell fragments including *Gemma Gemma.*	
		155-290 cm	Light gray very fine sand with very little mud.	Disarticulated shells (*Mercenaria* sp.) at 212 and 285 cm.	
		290-387 cm	Dark gray mud grading to sandy mud.		
		387-454 cm	Light gray medium to coarse sand.	Top of Pleistocene. Small mud lenses (borings) at 397,410,433,435, and 450 cm.	
MBDD06/7	471 cm	0-42 cm	Light tan grading into light gray muddy fine to medium sand.		-0.16 m
		42-129 cm	Very dark brown mud.	Modern pocosin or possibly Pleistocene equivalent.	
		129-152 cm	Very dark brown humic-rich muddy sand.	Pleistocene sediment similar to humic-rich sand facies of Neuse Formation.	
		152-185 cm	Dark brown coarse sand with scattered quartz granules.		
		185-286 cm	Light gray medium sand.	Coarse shell hash between 268-286 cm.	
		286-471 cm	Light gray fine sand with minor amounts of shell fragments.	Mud lenses (borings) at 431,438, and 443 cm.	

Appendix C. (Continued).

Core-ID	Length		Description	Comments	Elevation
MBDD08	503 cm	0-100 cm	Dark gray muddy fine sand grading into light gray fine sand.	Cluster of disarticulated shells between 87-96 cm.	-0.53 m
		100-224 cm	Medium gray slightly variegated muddy fine sand grading into bluish green variegated fine sandy mud.	Top of Pleistocene. Contains multiple orange-brown oxidation spots. Small section of over-compacted mud between 132-144 cm contains plant material.	
		224-301 cm	Dark gray muddy fine sand.	Pleistocene sediments.	
		301-327 cm	Medium gray fine sand with abundant shell hash.	Pleistocene sediments.	
		327-414 cm	Medium gray fine sand.	5x2 cm shell (Tagelus) at 344 cm. Woody material at 346 cm.	
		414-503 cm	Medium gray overcompacted mud.	~2 cm shell at 450 cm. Brown staining and small woody rootlets at base of unit.	
MBDD09	376 cm	0-8 cm	Dark brown muddy fine sand.	Contains marsh rootlets. Top 4 cm of core containing marsh mud was cut off.	-0.05 m
		8-71 cm	Light gray clean fine sand.		
		71-87 cm	Light gray fine sand with moderate shell hash.	Contains 2 cm length rootlets.	
		87-102 cm	Light gray coarse sand with abundant shell hash.		
		102-154 cm	Light gray fine sand grading to dark gray sandy mud.		
		154-205 cm	Dark gray sandy mud grading to dark gray mud.	Disarticulated shells at 158,165, and 180 cm. Large shell (*Tagelus*) between 191-201 cm.	
		205-376 cm	Dark gray mud grades into light gray clean fine sand.	Top of Pleistocene. Mud lenses (borings) at 334 and 352 cm.	

Appendix C. (Continued).

Core-ID	Length		Description	Comments	Elevation
MBDD10	87 cm	0-20 cm	Dark brown mud.	Modern estuarine fill. Large pieces of *Spartina* sp. roots.	+0.51 m
		20-44 cm	Medium gray medium sand.	Some plant rootlets.	
		44-51 cm	Dark brown mud.	Abundant *Spartina* sp. roots.	
		51-74 cm	Medium gray fine to medium sand.	Contains small rootlets.	
		74-87 cm	Dark brown humic-stained fine to medium sand.	Core hit something very hard at 87 cm; potentially a rock or debris from nearby homes as this is a mainland core.	
MBDD11	335 cm	0-12 cm	Dark brown to black fine sandy mud. Grades into lower unit.	Modern estuarine fill. Contains plant rootlets.	+0.57 m
		12-37 cm	Medium gray medium sand.	Contains small rootlets.	
		37-65 cm	Medium gray fine sandy mud.	Contains large *Spartina* sp. roots.	
		65-198 cm	Dark brown to black humic-rich muddy fine sand grading into variegated fine sand. Unit then grades into light gray clean fine sand with light brown clean fine sand composing last 10 cm of unit.	Top of Pleistocene. Variegation likely due to leaching of humate material through soil.	
		198-199 cm	Small layer of humic-rich fine sand.	Contains some well rounded tabular quartz pebbles ~1 cm in diameter.	
		199-220 cm	Light brown very fine sand.		
		220-238 cm	Light gray to light brown medium sand.	Rounded quartz pebbles ~0.8 cm in diameter.	
		238-335 cm	Light brown very fine sand grading into light gray very fine sand.	Orange-brown horizontal stains at 279,290,297, and 315 cm.	

Appendix C. (Continued).

Core-ID	Length		Description	Comments	Elevation
MBDD12	371 cm	0-35 cm	Dark gray to brown very fine sandy mud.	15 cm march plug cut from top of core. Unit contains small rootlets.	-0.23 m
		35-245 cm	Light gray very fine clean sand.		
		245-324 cm	Dark gray to brown thick mud.		
		324-371 cm	Medium gray coarse sand with abundant shell hash.	Channel deposit or inlet fill.	
MBDD13	457 cm	0-45 cm	Dark brown muddy fine sand. Grades into underlying unit.	Mud snails (*Nassarius* sp.) at 43 cm.	-0.54 m
		45-156 cm	Light gray fine sand with decreasing mud content. Grades into light gray fine sand with very minor amounts of shell hash.	Channel deposit or inlet fill.	
		156-249 cm	Dark gray silty mud. Muddy fine sand at base of unit (237-249 cm).	Sharp contact with above unit. Abundant oyster shells.	
		249-422 cm	Dark gray variegated mud grades into muddy fine bluish gray sand.	Top of Pleistocene.	
		422-457 cm	Dark gray fine sandy mud.	Pleistocene sediments. Abundant oyster shells.	

Appendix C. (Continued).

Core-ID	Length		Description	Comments	Elevation
MBDD14	273 cm	0-33 cm	Dark gray to dark brown fine sandy mud.		-0.49 m
		33-110 cm	Dark gray to dark brown muddy fine sand grading into clean light gray fine sand.		
		110-149 cm	Light gray fine to medium sand with moderate shell hash.	Channel deposit or inlet fill.	
		149-157 cm	Light gray fine sand grading into underlying unit.	Disarticulated shell cluster between 149-157 cm.	
		157-189 cm	Dark brown to dark gray fine sandy mud.	Top of Pleistocene.	
		189-273 cm	Light gray-greenish blue silty mud grades to same color very fine sand.	Pleistocene sediments. Rootlets present between 205-215 cm.	
MBDD15	302 cm	0-25 cm	Dark gray fine sand with minor shell hash.		-0.07 m
		25-37 cm	Dark gray fine sandy mud.		
		37-170 cm	Light gray clean fine sand grading into light gray medium to coarse sand.	Channel deposit or inlet fill. Cluster of oyster shells between 69-74 cm. Marsh mud inclusion at 130 cm.	
		170-292 cm	Light gray clean fine sand.	Channel deposit or inlet fill. Large shell (5x2 cm) at 270 cm.	
		292-302 cm	Light brown medium sand.	Large (7 cm) shell (*Mercenaria* sp.) at base.	

Appendix C. (Continued).

Core-ID	Length		Description	Comments	Elevation
MBDD16	421 cm	0-53 cm	Dark brown mud.	Modern estuarine fill with abundant *Spartina* roots.	+0.29 m
		53-113 cm	Medium to dark brown muddy fine sand grading into light gray clean fine sand.		
		113-177 cm	Light gray fine to medium sand with abundant shell hash.	Channel deposit or inlet fill.	
		177-421 cm	Light to bluish gray variegated fine sandy mud. Grades into silty mud of same color and then grades into dark gray muddy fine sand.	Top of Pleistocene. No shell material.	
MBDD17	96 cm	0-46 cm	Coarse shell hash and very coarse sand.	This core was taken from the beach face.	+0.86 m
		46-73 cm	fine to medium sand with abundant large shell fragments.		
		73-81 cm	Dark brown organic rich mud.	Abundant rootlets.	
		81-96 cm	Humic-rich fine sand.	Top of Pleistocene. Contains some small rootlets.	

BIOGRAPHICAL SKETCH

S. David Doughty was born on July 15, 1977, in Valdosta, Georgia. He graduated from Western Carolina University in May 2002 with a B.S. degree in geology. Mr. Doughty entered the graduate program in geology at the University of North Carolina at Wilmington in August 2002 where he worked under the direction of Dr. William J. Cleary. He was a graduate teaching assistant for two years during which time he taught introductory geography labs. In May 2004, he was awarded a fellowship position from the National Science Foundation where he served as science resource person in local middle schools. Mr. Doughty graduated in 2006 with a M.S. in Geology. He and his wife Melissa currently live in Naples, Florida where he works as a coastal geologist for Coastal Engineering Consultants, Inc.