Shoreline Restoration in High Hazard Zones: Southeastern North Carolina, USA

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ABSTRACT


A number of high-risk segments along southeastern North Carolina have partially recovered from the impacts of the hurricanes in the late 1990s; however many severely impacted areas are still at risk. A primary management concern related to these high hazard areas, is the controversial issue of beach nourishment. More than 80% of the 180km long shoreline between Cape Lookout and Cape Fear is extensively developed. All communities that comprise this reach are involved in some form of replenishment activities ranging from feasibility studies to major nourishment projects. Aside from the financial aspects of nourishment, many communities are concerned with the availability of sand resources for nourishment programs. Long-term chronic erosion and the lack of significant recovery have prompted a re-examination of offshore areas for sand resources for erosion and storm damage reduction projects. Many of these sediment-starved reaches have little storm protection in place and have a marginal potential for locating suitable beach fill resources for nourishment purposes. Consequently, major sections of some high hazard reaches will have to be abandoned, as relocation is not an option. The study focuses on Topsail Island, a 40 km long transgressive barrier, as an exemplary barrier setting where three communities with different environmental and erosion histories are confronted with identifying large volumes of sand to meet their nourishment needs.

INTRODUCTION

Southeastern North Carolina is a prime example of a coastal area that has experienced rapid population growth and increased tourism revenues. The growth of all coastal communities is tied directly to the presence of wide oceanfront beaches. Therefore, the management and the costly maintenance of the oceanfront beaches are primary concerns to local communities and coastal managers.

Currently the State of North Carolina has one of the most restrictive shoreline stabilization policies in the USA. Other than the relocation of erosion threatened homes, the only other viable option for erosion mitigation is beach nourishment. By some accounts tourism generated revenues approach one billion dollars. Consequently, most communities are involved in some form of replenishment activities. In addition to the financial and environmental aspects of nourishment, all communities are concerned with the availability of sand for beach fill operations. The long-term chronic erosion, coupled with the impacts of four landfalling hurricanes in the late 1990s, has prompted a regional examination of sources for beach fill quality sand for construction of storm-damage reduction projects. Although significant volumes of beachfill materials are available within the estuarine waters, severe environmental restrictions limit the use of these areas as primary sources for major beachfill operations. The restrictions have led to the targeting of tidal inlets and the shoreface as potential borrow sources. Many shoreline reaches in the area are sediment starved, have little storm protection in place, and have a marginal potential for locating suitable sand resources for long-term (30 to 50 years) nourishment programs. As a consequence, major segments of some of the high hazard reaches will have to be abandoned, as relocation of most of the structures is not an option. This study focuses on Topsail Island, a 40 km long transgressive barrier, as an exemplary setting setting where communities are confronted with identifying large volumes of sand to meet their nourishment needs (Figure 1). The three communities that comprise this reach (North Topsail Beach, Surf City and Topsail Beach) have different erosion histories, storm responses, underlying geologic constraints and nourishment needs and potentials.

STUDY SITES SETTING

The shape of the North Carolina coastal system reflects major differences in the underlying geological framework (Riggs et al., 1995). Cape Lookout separates the 525 km coast of North Carolina into two distinct provinces. The coastal system south of Cape Lookout (Figure 1) is underlain by Miocene to Pleistocene age rock units (Snyder et al., 1982; Snyder et al., 1994; Cleary et al., 1996). The underlying units are composed of rocks associated with the Carolina Platform, which underlies the Cape Fear, NC region. This structural platform has risen slightly over geologic time resulting in the truncation of the rock units by the migrating shoreface. Consequently, an erosional topography exists with only a thin veneer of sediment and widespread exposures of rocks across the shoreface (Riggs et al., 1995).

Narrow barriers and spits that comprise the region are "perched" on older geologic units that constitute the shoreface (Cleary and Hosier, 1987; Riggs et al., 1995). A paleodrainage system consisting of a series of large-scale river valleys is incised into the underlying Tertiary units (Riggs et al., 1995). This drainage network has controlled the development of large-scale topography and the formation of a series of non-headland and headland segments.

A number of headlands exist where the underlying rock units crop out as submarine features. The units extend beneath the barrier and crop out on the shoreface forming a headland such as the shoreline segment along a portion of North Topsail Beach (Crowson, 1980; Cleary and Hosier, 1987; Riggs et al., 1995; Cleary et al., 1996; Johnston, 1998; Cleary et al., 2001). Non-headland shoreline segments such as Surf City and Topsail Beach are the more common shoreline type within the region. These reaches are generally underlain by inlet-fill or transgressive sequences.

Topsail Island and Topsail Beach Setting

Topsail Island is located within the central portion of Orslow
bay and is the second longest barrier in the region (Figure 1). The island consists of three communities: North Topsail Beach, which comprises the northern 18.7 km section, Surf City, which covers the central 5.8 km of the barrier, and Topsail Beach, which extends along the southern 7.2 km of the island. The island is bordered by New River Inlet to the north and New Topsail Inlet to the south. Development of the island began in the early 1950's. Storms occurring between 1944 and 1962, and during the late 1980's were particularly devastating. In addition to the tropical storms ~ 15 nor'easters impact the island on an annual basis. During HURRICANES FRAN, BONNIE, and FLOYD (1996-99) much of the island was overtopped, resulting in the formation of massive and extensive washover topography.

**NORTH TOPSAIL BEACH**

North Topsail Beach comprises the northern section of the barrier, and is situated in a high hazard zone. This section of the barrier, even prior to 1996, was considered to be a high-risk zone. Hurricane Bertha (7/96) eroded a significant portion of the dune field. The small amount of shoreline recovery did little to improve the beach conditions before Hurricane Fran struck the area seven weeks later in early September 1996.

During Hurricane Fran much of the island was inundated resulting in the damage of a large number of homes, most utilities, and almost all of the fronting dunes. The extensive exposures of peat and stump forests on the foreshore clearly indicated that major segments of this barrier were poised for an accelerated increase in rollover rates. A minimum of six temporary inlets formed during (1999) as the barrier was again breached. Some of the breaches reoccupied former inlets opened during Hurricane Fran in 1996.

In the aftermath of Hurricanes Fran and Floyd, much of North Topsail Beach resembled an extensive washover terrace (CLEARY and PILKEY, 1996; YOUNG, et al., 1999; and CLEARY, et al., 2001). Numerous winter storms punctuated the intervals between Hurricane Bonnie in 1998 and Hurricanes Dennis and Floyd in 1999.

Realignment of the outer bar channel of New River Inlet has promoted significant erosion of the beach and dunes along the shoreline segment downdrift of the inlet (Figure 2 (A) and (B)). Since 1997, shoreline retreat has ranged from 14.55 m along the 1.5 km long shoreline reach downdrift of the inlet. In May 2002, ~235,000 m$^3$ of material was placed along the eroding shoreline in a futile attempt to mitigate the inlet-related erosion.
Surf City

Surf City occupies the central 8.7 km of Topsail Island (Figure 1). The majority of the barrier in this vicinity fronts the relict flood-tidal deltas of Stumpy Inlet (18° and 19° C). Finger canals were dredged in the mid to late 1960's across the surface of the marsh that caps the coalesced flood tidal deltas. The dunes prior to the landfall of Hurricane Bertha in July 1996 were low, scattered and often scarped. HURRICANES BERTHA and FRAN (1996) eroded most of the oceanfront dune field particularly along the northern portion of the community. Washover terraces extended across much of the low-lying areas (Figure 3 (A)). The southern portion of Surf City was less susceptible to overtopping, and overwash penetration was greatly reduced due to the topographically higher foredune and adjacent dune field. A continuous, relatively low-relief, restored foredune currently fronts much of the Town's oceanfront.

Top sail Beach

Extensive beachfront development along Topsail Beach began in the 1950's. The cottages that date from this period were constructed on the primary dune that paralleled the shore-normal to shore-oblique rippled channel-like depressions. The Trent Formation, which is compositionally similar to the Belgrade Limestone, crops out over a significant portion of the shoreface. A second major stratigraphic unit, the Oligocene River Bend Formation, also underlies a major portion of the area. The highly irregular karstic surface is characterized by a series of low- (0.50 m) to high-relief (2.0 m) hardbottom scarps and intervening flat areas. The high relief features are more common in the vicinity north of New River Inlet. The relief and frequency of high relief scarps decreases in a southerly direction where low-lying hardbottoms are the more common shoreface feature (JOHNSTON, 1998). Vibracoring operations and diver mapping surveys indicated that the sediment cover on the shoreface is extremely thin (<0.20 m). A significant portion of the shoreface consists of barren limestone. Several cores were recovered from the paleo-channel of New River (MEISBURGER, 1979). The data suggested that this very restricted region off New River Inlet was the only area on the northern part of the shoreface where sand deposits may be preserved. However recently recovered cores indicated there is a paucity of sediment in the area.

New River Inlet ebb-tidal delta which rests atop the limestone platform is estimated to contain ~7 million m³ of sediment to water depths of 6m. This Inlet related sand body represents the only viable source for the nourishment of North Topsail Beach.

The shoreface offshore North Topsail Beach has a very low potential for providing significant volumes of beach fill quality sand (CLEARY and RIGGS, 1999; CLEARY et al., 2001; and HDR, 2002b). An absence of sand-filled, paleo-channels coupled with the ubiquitous presence of hardbottoms precludes the use of the shoreface as a borrow area. The New River Inlet ebb-tidal delta represents the only significant and renewable source for high quality, beach fill sand, available for mitigation purposes. However, slight changes in the size and shape of the ebb-tidal delta related to dredging will significantly affect the shorelines of the adjacent barriers. Changes will stem from altering the shoal's breakwater effect, sediment transport patterns and the locations of swash bar attachment.

METHODS

The study sites consist of a series of diverse barrier segments for which there are a variety of data. The database for this study consisted of both published and unpublished information. The published investigations include those of MIESBERGER (1979); CLEARY and HOSIER (1987); JOHNSTON (1998) and CLEARY et al., (2001). Unpublished reports include MCGUARREY (1998); CLEARY and RIGGS (1999); and HDR Engineering Inc. Of the Carolinas (HDR) (2002a and b). Data from these investigations were supplemented by additional geological and geophysical data derived from recent surveys.

RESULTS AND DISCUSSIONS

North Topsail Beach

The shoreface in the northern part of the area is dominated by a platform-like submarine headland composed of a well-indurated Oligocene bio-moldic limestone. This unit forms the majority of the limestone platform that controls the bathymetry of the area. The highly irregular karstic surface is characterized by a series of low- (0.50 m) to high-relief (2.0 m) hardbottom scarps and intervening flat areas. The high relief features are more common in the vicinity north of New River Inlet. The relief and frequency of high relief scarps decreases in a southerly direction where low-lying hardbottoms are the more common shoreface feature (JOHNSTON, 1998). Vibracoring operations and diver mapping surveys indicated that the sediment cover on the shoreface is extremely thin (<0.20 m). A significant portion of the shoreface consists of barren limestone. Several cores were recovered from the paleo-channel of New River (MEISBURGER, 1979). The data suggested that this very restricted region off New River Inlet was the only area on the northern part of the shoreface where sand deposits may be preserved. However recently recovered cores indicated there is a paucity of sediment in the area.

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Surf City

The morphology of the shoreface off Surf City is similar to that offshore North Topsail Beach. Differences that occur reflect the lack of high relief hardbottoms (>2 m) and the presence of rippled channel-like depressions. The Trent Formation, which is compositionally similar to the Belgrade Limestone, crops out over a significant portion of the shoreface. A second major stratigraphic unit, the Oligocene River Bend Formation, also underlies a major portion of the area. Vibracores recovered from widely scattered sites indicated the River Bend Formation consisted of an olive green, very fine, calcareous quartz sand and dolomitic, quartz silt (HDR, 2002 b).

The sea floor in the southern portion of the study area consisted of isolated, irregular areas of 1.6 to 3.2 km wide fields of shore-normal to shore-oblique rippled channel-like depressions interspersed amongst areas of low relief limestone hardbottoms. The distribution of the major surface sediment types is complex and is dictated by the spacing, relief, and composition of the rock exposures and subcrop units.
The Holocene sediment sequence is thin and consists of units of fine quartz sands intercalated with gravel mixtures. Mud-rich and silty back barrier sequences were recovered in a large number of vibracores retrieved from the shoreface off Stump Sound (Figure 4). Thickness of the modern sediment package ranged from less than 1.0 cm in hardbottom areas to more than 1.9 m in intervening sediment filled depressions. The thickest modern sediment sequences cored (0.50 to 6.35 m) were recovered from mud-filled paleo-channels. The majority of the individual sedimentological units present in most cores are less than 0.40 m thick. Gravel rich units are widespread and comprise major portions of the thin sequences and were typically found in areas where limestone forms the subcrop unit and near limestone hardbottoms.

Much of the shoreface off Surf City is covered by sediment sequences less than ~30 cm thick. The area with the thickest deposits of sediment (>1.0 m) is restricted to a small region located within the central portion of the shoreface offshore Stump Sound (Figure 4). This highly irregular region is underlain by siltstone. A second area where relatively thick sediments are found is located offshore the southern portion of Surf City. The USACE recently conducted vibracoring operations in the aforementioned areas and recovered ~100 cores that contained either 2-5 m of Holocene, fine-grained estuarine sequences, consisting mostly of interbedded silt and mud, or thin Holocene sediment sequences overlying Oligocene siltstone. All cores sited in paleo-channels recovered Holocene sequences comprised of either organic-rich mud/peat or dark gray clay sequences with scattered oyster shells units.

The nourishment needs for Surf City during the next 30-50 years is estimated to exceed 10 million m$^3$. The shoreface offshore Surf City has a low potential for providing significant volumes of quality material for beach fill operations even though the shoreface in underlain by relatively thick Holocene sediment sequences (CLEARY et al., 2001 and HDR, 2002b). The silt-rich sediment sequences coupled with the presence of limestone hardbottoms preclude the use of the shoreface as a potential long-term borrow source. The location of the community along the mid-barrier portion of the Topsail Island only amplifies the sand shortage problem over the long term.

**Topsail Beach**

Oligocene age limestone and siltstone units correlative to those offshore Surf City form the outcrop and subcrop units off Topsail Beach (MCQUARRIE, 1998 and HDR, 2002a). A variety of Holocene and Pleistocene age paleo-fluvial channels are incised into the rock units, particularly the Oligocene siltstone sequence. Vibracore data indicated that almost all of the channels were filled with estuarine mud and silt. Sidescan sonargraph data indicated several distinct zones of seafloor morphology occur offshore Topsail Beach. The northern portion of the shoreface is characterized by a patchy distribution of low-relief, limestone hardbottoms mantled with a thin veneer of sand and gravel. An extensive contiguous exposure of limestone occurs offshore the southern 3.5 km of island. Fields of linear channel-like depressions, characterized by high acoustic reflectance, flank the hardbottom areas. Many of the linear channel-like depressions are floored with ripped, very coarse shell and lithic gravels. The shoreface south of New Topsail Inlet is underlain by the Oligocene siltstone that crops out intermittently.

The sediment cover is patchy and highly variable in thickness. The majority of the sand units are less than 0.50 m thick. Gravel-rich units are widespread and comprise a major portion of the sediment sequence particularly near hardbottoms. Thicker Holocene sediment accumulations (>2 m) appear to be confined to broad depressions between major limestone hardbottoms. These isolated highly irregular sediment ponds areas are underlain by easily eroded siltstone and are sites where discontinuous remnants of Holocene estuarine lithosomes are preserved.

It was initially hypothesized that beachfill quality sand may be available in significant quantities in four extensive target areas on the outer shoreface and offshore New Topsail Inlet.
potential for sand resources in the offshore area. Furthermore, because of its location along the mid barrier portion of the island, the likelihood of utilizing inlet related sand bodies at New River and New Topsail Inlets is extremely low due to the high costs and demand for the resources by other communities. Topsail Inlet, in a relative sense has the best potential of the island’s communities for nourishing the oceanfront beach. However routine maintenance of adjacent New Topsail Inlet and its access channels will provide only a small portion of the material needed to adequately nourish the beach over the next 30 years. If the resource potential of the shoreface immediately seaward of the inlet proves to be low, then abandonment of structures in the oceanfront high hazard areas will occur within the next several years as storms impacts take their toll.

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LITERATURE CITED


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Figure 5. Map depicting target areas on shoreface and areas of thin sediment accumulation offshore Topsail Beach.


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