SHORELINE CHANGE WITHIN THE ALBEMARLE-PAMLICO ESTUARINE SYSTEM, NORTH CAROLINA

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Front Cover Photo. A drowning forest in the Neuse River Estuary new New Bern. Photo by David Kunz

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A White Paper by
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EXECUTIVE SUMMARY

Coastlines are constantly changing due to both natural and anthropogenic forces. On-going climate change and associated sea-level rise are reshaping our coasts. However, the oceanfront is not the only concern. Shoreline dynamics along more sheltered estuaries, like those along the Albemarle-Pamlico Estuarine System (APES) of North Carolina, have gained attention. We need to better understand and manage these boundary resources that area a critical habitat for a variety of ecosystem goods and services. Research conducted on the Neuse River Estuary demonstrates the dominance of erosion along the shore of our estuaries, regardless of shore-type (e.g., marsh, beach, bluff). Erosion rates greater than 10 feet per year over a 40 year period were measured using aerial photography from 1958 and 1998. An average erosion rate of ~1 foot per year was calculated for the entire Neuse River Estuary. These erosion rates have led property owners to attempt to halt the loss of their water front by means of shoreline stabilization structures (i.e., riprap, sills, seawalls, etc.). About 30% of the shoreline along the Neuse River Estuary has been modified with stabilization structures with little understanding of the short-term ecological impacts or the long-term effects associated with on-going climate change and sea-level rise. It is imperative that we better understand the potential changes coastal North Carolina faces in the near future so that we can manage the natural resources appropriately.

INTRODUCTION

Key Terms

Shoreline: the physical interface between land, air, and water.

Shorezone: the land area that extends from an estuarine shoreline landward to where the hydrologic influence of sea level diminishes and terrestrial hydrology dominates.

Ecosystem goods and services: the end products of natural ecosystems that yield human well-being and value (e.g., fish from the sea, beauty of the coast). Conditions that define an ecosystem service include: (1) the service originates from the natural environment; (2) the service enhances human well-being; and (3) the service is an end product of nature directly used by people.

Affected by a diversity of natural and anthropogenic processes, coastal areas are dynamic systems that are heavily populated. Excluding Alaska, coastal counties comprise 17% of the nation's land, yet they contain over 50% of the United States population (based on 2003 census data, Crossett et al. 2004). Crossett et al. (2004) determined that the national average population density (excluding Alaska) is 98 people per square mile for non-coastal counties, as compared to 300 persons per square mile for coastal counties. Consequently, the development and management of coastal areas is of great concern, especially in light of our demonstrably changing climate.

Sea-level variation is an important consequence of climate change, both for society and the environment. Estimates of global sea-level rise (SLR) for the 21st century ranges from 0.3 to 2.9 feet, but locally sea-level rise may be much higher or lower due to factors such as subsidence, sediment compaction, or uplift (IPCC, 2007). Many coastal areas will experience increased levels of flooding, accelerated erosion, loss of wetlands and low-lying terrestrial ecosystems, and seawater intrusion into freshwater sources as a result of SLR and potentially enhanced storm frequency and severity. Prediction of shoreline retreat and land loss rates is critical for planning of future coastal zone management strategies, and to assess biological impacts due to habitat changes and loss (Thieler and Hammer-Klose, 1999).

The Albemarle-Pamlico Estuarine System (APES) of North Carolina is the second largest estuary in the United States and contains extensive estuarine marshes that provide critical habitat for a variety of ecosystem goods and services. Based on tide gauge measurements analyzed by the National Ocean and Atmospheric Administration (NOAA, 2004), the measured rate of relative SLR in North Carolina ranges from 0.07 to 0.17 inches per year with rates increasing from south to north. The rise in sea level coupled with storms over the last several decades already has had major impacts on North

Figure 1. Images of shoreline recession in the modern northeastern North Carolina estuarine coastal system as a result of storm processes and ongoing sea-level rise.

Carolina's mainland estuarine coastlines (Figure 1). Rates of shoreline recession are a function of shoreline type, geometry and composition, geographic location, size and shape of the associated coastal water body, coastal vegetation, water level, and storm frequency and intensity, all of which vary dramatically alongshore (Riggs and Ames, 2003). With SLR and shoreline recession, the function of any shorezone may be significantly altered by the transformation from one ecosystem class to another (e.g., from wetlands to open water) (Brinson et al., 1995).

Ultimately, to manage our coastal estuarine resources wisely and to maximize human utilization, long-term solutions to estuarine shoreline erosion problems must be in harmony with the dynamics of the entire coastal shoreline and shorezone system. This document summarizes the results of a multi-year, multidisciplinary study funded by NOAA and designed to address this need. The overall goal of the project was to evaluate mainland shoreline and shorezone compositional changes over four decades (1958-1998) within the Neuse River Estuary, a major component of the APES (Figure 2).

NORTH CAROLINA'S ESTUARINE SHORELINE

Due to the low topographic slopes on the coastal plain (less than 0.3 feet elevation for every horizontal mile), much of the coastal zone in northeastern North Carolina is within a few feet of current sea level (Figure 2). As a result, shoreline recession has consumed approximately 50 square miles of coastal lands over the past 25 years, more than half of which are critical wetland environments (Riggs and Ames, 2003). We cannot stop this natural process of estuarine shoreline recession in North Carolina. However, better knowledge of the consequences of SLR and associated shoreline recession would be economically, socially, and environmentally advantageous. Below we summarize factors critical to understanding shoreline change and the dynamics of the estuarine shorezone in northeastern North Carolina estuaries.

Previous Work on Estuarine Shoreline Change

North Carolina's coastal zone (e.g., sounds and estuaries) are a product of post-glacial SLR and flooding of the stream valleys of the drainage systems. Estuarine shorezones have been geomorphologically classified into four basic categories: sediment bank, organic, combination, and back-barrier shorelines (Figure 3; Table 1; Riggs and Ames, 2003). Sediment bank shorezones tend to be steeply sloping, and often have a wave-cut scarp.

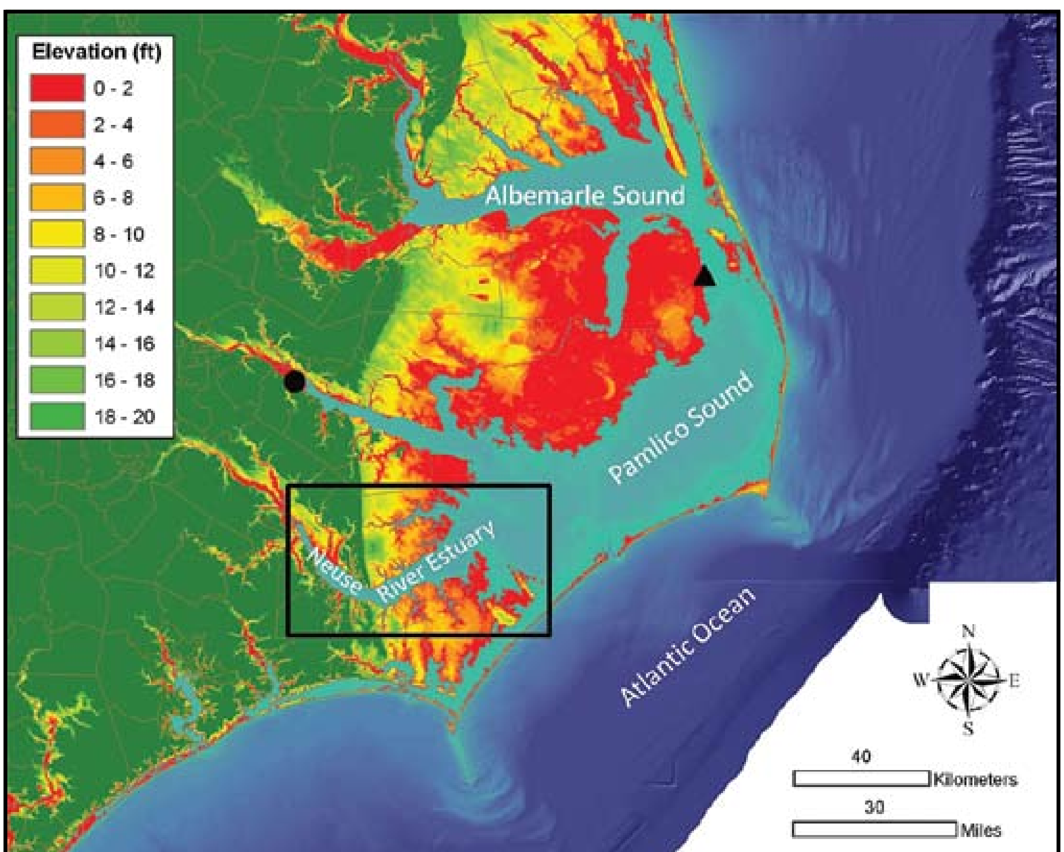

Figure 2. Elevation (LiDAR) map of coastal North Carolina showing the Albemarle-Pamlico estuarine system. Note that much of the region is extremely low lying (less than 2ft above sea level) and extremely susceptible to modification by storms and sea-level rise. The closed triangle and circle denote Point Peter Road and Bay Hills, respectively. The black box indicates the area shown in Figure 4 and 5.

Table 1. Shoreline categories in the Albemarle-Pamlico Estuarine System and their defining parameters (modified from Riggs and Ames, 2003).

SHORELINE CATEGORIES	SHORELINE SUB-TYPE	DEFINING PARAMETERS
Sediment Bank Shorelines	Bluff	Greater than 20 feet
	High bank	5-20 feet
	Low bank	Less than 5 feet
Organic Shorelines	Swamp forest	Freshwater riverine floodplains and freshwater pocosins
	Marsh	Fresh, brackish, and salt waters
Combination Shorelines	Sediment bank with cypress fringe	
	Sediment bank with marsh fringe	
	Sediment bank with fringe of log and shrub debris	
	Low sediment bank with stumps	
	Swamp forest with strandplain beach	
	Marsh with strandplain beach	
	Human-modified shoreline	
Back-Barrier Shorelines	Overwash barriers	Sand fans and platform marshes
	Complex barriers	Sediment banks and organic banks
	Inlet	Flood-tide deltas

Sand that forms the beach is derived from erosion of the adjacent sediment bank (Figure 3 A, B). Organic shorezones consist of water-tolerant flora, including grasses (e.g., smooth cordgrass and salt meadow cordgrass: *Spartina alterniflora* and *Spartina patens*), rushes (e.g., black needlerush: *Juncus roemerianus*), shrubs (e.g., marsh elder: *Iva frutescens*) that grow at the land/water interface and are capable of withstanding extended periods of flooding by water with variable salinities. In freshwater areas, trees (e.g., bald cypress and water tupulo: *Taxodium distichum* and *Nyssa aquatica*) form extensive swamp forest wetlands. Estuarine marsh shorezones occur throughout most of the estuarine system (Figure 3 C), but swamp forest

Figure 3. Photographs show four different types of shorezones within the Albemarle-Pamlico estuarine system (Riggs and Ames, 2003): A) high sediment bank; B) low sediment bank being converted to a freshwater marsh; C) platform marsh shoreline retreating into a swamp forest; and D) pocosin swamp forest receding shoreline common in fresh water portions of the APES region.

shorezones are restricted to the freshwater areas (Figure 3 D). Combination shorezones are those of diverse composition (including human modification) and are present throughout the NC coastal system.

Most estuarine shorelines in North Carolina are eroding in response to the interaction of storms and sea-level rise. However, previous studies indicate that shoreline erosion is extremely variable from site to site with significant ranges in erosion rates evident over short distances (Riggs, 2001; Riggs and Ames, 2003). The site with the highest average rate of recession in the Riggs and Ames (2003) study was the platform marsh at Point Peter Road (Pamlico Sound; see Figure 2 for site location) with an average recession rate of -7.5 feet per year in contrast to the lowest average recession rate of less than -1 foot per year along the bluff shoreline at Bay Hills (head of Pamlico River; see Figure 2 for site location). Shoreline change rates varied from 0 feet per year during periods of low storm activity to a high of -26 feet per year (erosion) along the sand bluffs at the north end of Roanoke Island during periods of high storm activity. Riggs and Ames (2003) determined that the average annual estuarine shoreline change rates for specific shoreline types ranged between +0.6 feet per year (accretion) for back-barrier beaches to -3.3 feet per year (erosion) for the mainland marshes.

From the Riggs and Ames (2003) data, several important patterns concerning average annual shoreline erosion rates for major shoreline types and estuarine regions are obvious. Mainland marsh and low sediment bank have the overall highest average rates of estuarine shoreline recession (-3.3 feet per year). They are also the most abundant shoreline types, constituting about 85% of the coastal system in northeastern North Carolina. Bluffs and high sediment banks, with their available sand, debris and vegetation, are less abundant (about 8%) and generally erode more slowly (-2.6 feet per year) compared to low sediment banks. Swamp forest shorelines are the least abundant (about 7%) and erode the slowest (-2.3 feet per year) due to their lack of elevation and low offshore gradients together with the role of trees in abating wave energy. Based upon this and other studies, several physical variables have been identified that act to shape/modify the shoreline as sea-level rises, producing alongshore variability in erosion rates (Table 2). The research presented below builds on this significant body of previous work.

Table 2. Physical variables shaping estuarine shorelines (modified from Riggs and Ames, 2003).

SHORELINE VARIABLES	DEFINITION	POTENTIAL FOR EROSION LOW	HIGH
Fetch	Average distance of open water in front of shoreline	Short Fetch (<1000 feet)	Long Fetch (>1000 feet)
Offshore bottom character	Water depth and bottom slope in the nearshore area	Shallow, gradual slope (<3 feet)	Deep, steep slope (>3 feet)
Geometry of shoreline	Shape and regularity of shoreline (sinuosity)	Highly irregular or in a cove	Straight or on a headland
Height of sediment bank	Bank height at shoreline or immediately behind sand beach	High (>6 feet)	Low (<6 feet)
Composition of sediment bank	Composition and degree of cementation of bank sediments	Rock, tight clay	Uncemented sand, peat
Fringing vegetation	Type and abundance of vegetation (aquatic plants, marsh grasses, shrubs, trees, etc.) occurring in front of sediment bank	Very abundant, dense	Absent
Boat wakes	Proximity of property to, frequency and type of boat channel use	Absence of boats	Marinas, intracoastal waterway
Storms	Storms are the single most important factor determining specific erosional events	Depends on type, intensity, duration and frequency of storms	

ANALYZING SHORELINE CHANGE

Shoreline change can be calculated through the time-series comparison of various data sets that include ground surveys, aerial photography, satellite imagery, synthetic aperture radar, light detecting and ranging (LiDAR), and global positioning system. Although new satellite and other remotely sensed approaches are becoming feasible (e.g., LiDAR surveys, see Li et al. 2001), aerial photography analysis remains the most commonly used method to calculate shoreline change (Boak and Turner, 2005).

Spatial and temporal errors exist when using aerial photography to calculate shoreline change. Spatial distortion includes tilt, radial distortion, and relief displacement. However, these distortions are generally corrected when the image is rectified. Rectification gives the image a spatial reference and is necessary before shoreline demarcation. Since aerial photographs are a snapshot in time of a dynamic system, it is important to consider the events occurring just prior to the capture of the image (e.g., storms, flood). Regardless, it is essential to document and understand both the storm-dominated shoreline processes and the chronic change over decadal timescales that reflect net long-term variability.

Evaluating changes in shoreline position using aerial photographs can be quite challenging and time-consuming. Briefly, for a recent study in the Neuse River Estuary funded by NOAA, shoreline change was evaluated using spatially-

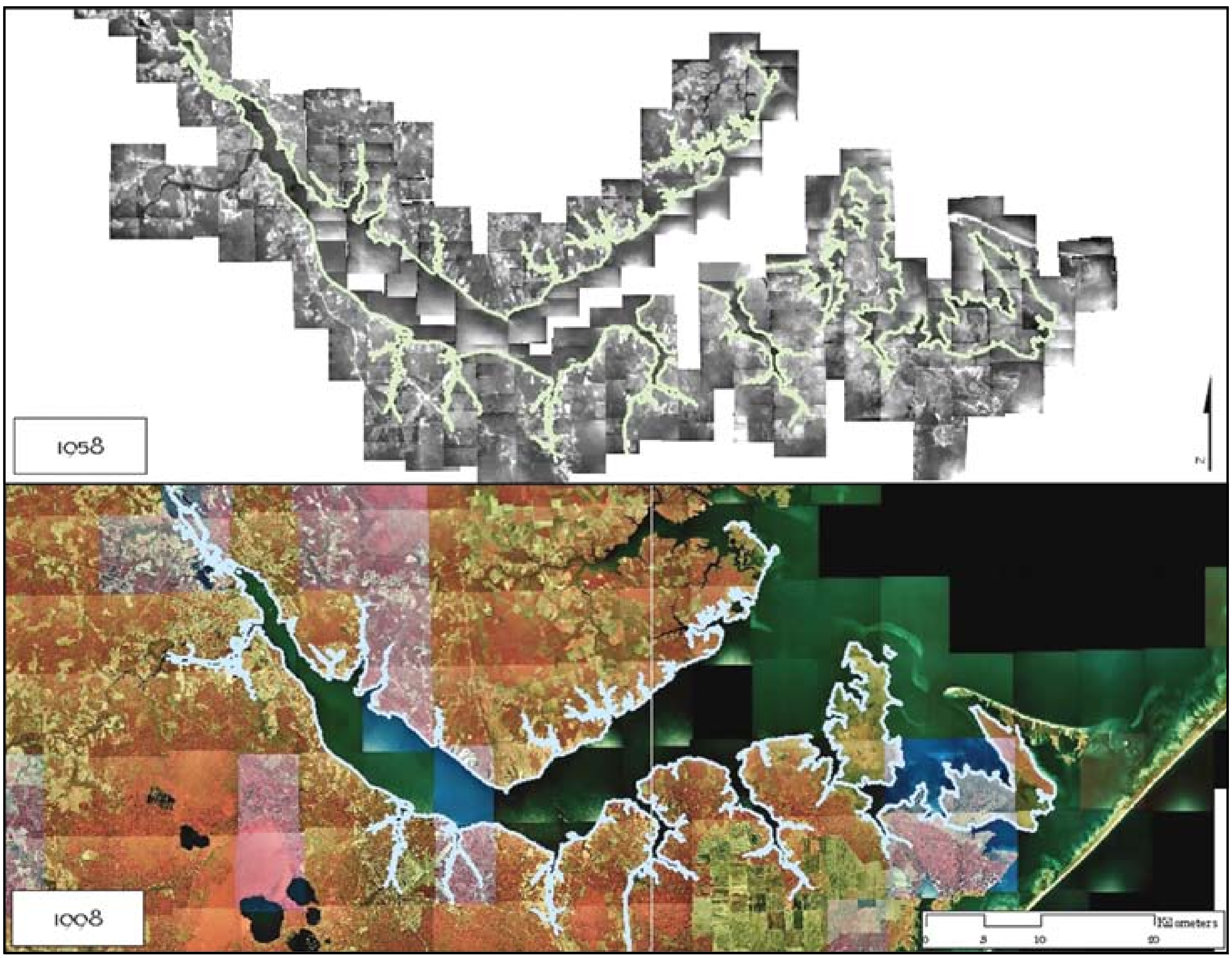

Figure 4. Representation of the areas that have been georectified and the associated digitized shorelines for the 1958 and 1998 aerial photographs of the Neuse River Estuary.

referenced aerial photographs from 1958 and 1998 time periods. The shoreline was digitally traced (outlined) using ESRI GIS and mapping software, ArcGIS®. Once the entire shoreline was digitized for the two different time periods (Figure 4), the difference in shoreline position was measured at 150-foot spacing along the entire shoreline for the 40-year period to determine the amount of either erosion or accretion and to calculate the rate of change (distance/time).

SHORELINE CHANGE IN THE NEUSE RIVER ESTUARY

Over 40 years (1958-1998), the vast majority (93%) of the Neuse River Estuary shoreline eroded (the shoreline moved landward). Only a small fraction (6.6%) of the shoreline accreted (the shoreline moved seaward), and less than 1% did not change (Figure 5). The rate of shoreline change varied widely from -11.5 feet per year (erosion) to +9.5 feet per year (accretion). The average shoreline change rate for the entire study area, including the protected tributaries, over the 40 year period was approximately -1 foot per year (erosion).

The rate of shoreline retreat is influenced by many factors, including but not limited to wave energy and duration, fetch of water that generates these waves, and boat wakes (Table 2). The influence of fetch, and therefore the resultant wave energy, can easily be seen in the erosion rates observed in the Neuse River Estuary. For example, some of the lowest erosion rates are found in the small tributaries and in head water portions of the estuary (symbols are mostly yellows and greens, Figure 5). In contrast, those areas along the main trunk of the estuary exposed to a fetch that included Pamlico Sound, had the greatest rates of erosion (Figure 5). This higher erosion rate along much of the Neuse River trunk is associated with the relentless wave attack during windy days and strong storms (e.g., hurricanes and nor'easters). With rising sea level and possible enhanced storm activity, it is highly probable that estuarine shoreline recession will become more severe in the near future.

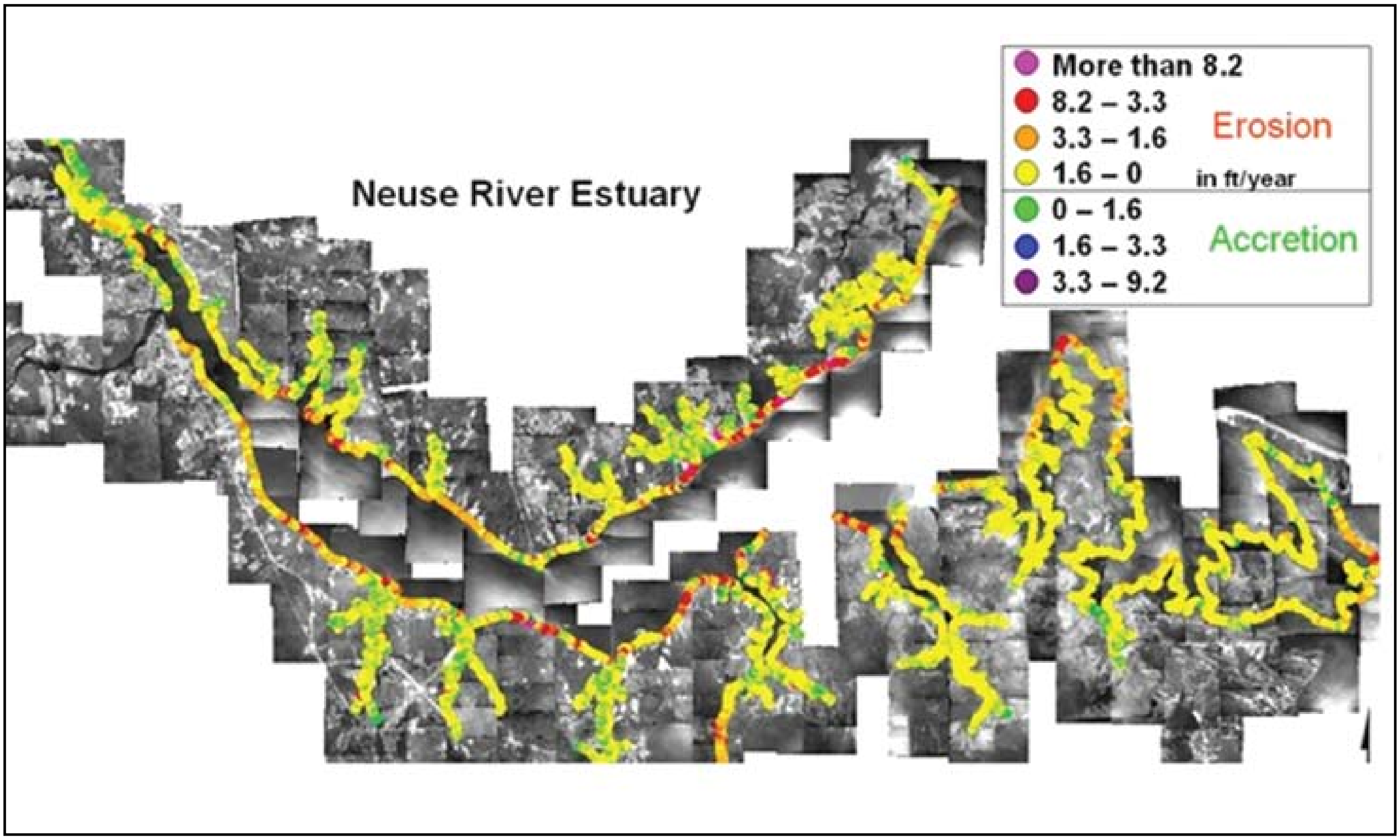

Figure 5. Map of shoreline change rate between 1958 and 1998 (40 years) along the Neuse River Estuary. Areas with higher erosion rates are denoted by yellow to pink, while areas that have accreted are represented by green to purple.

SHORELINE STABILIZATION

Shorelines within the APES are dynamic features that are receding significantly along most of the estuarine coast. Managing this coastal land loss is becoming ever more critical as coastal populations increase. The North Carolina Division of Coastal Management recognizes the importance of shoreline erosion management and recently established a working group charged with developing recommendations to guide the development of new estuarine shoreline stabilization rules. This Estuarine Biological and Physical Processes Working Group is providing guidance on the most appropriate stabilization method (Table 3) for different shoreline types. The number one recommendation for all estuarine shoreline types was land planning (i.e., leave the shorezone in its natural state). However, today this recommendation is not followed by most property owners along the trunk of the Neuse River Estuary. Recent mapping has shown that approximately 30% of the shoreline along the trunk of the Neuse River Estuary has been modified in an attempt to slow shoreline recession (Figure 6).

The desire to protect ones property is natural and logical; however, hardening of the shoreline has major consequences and should only be undertaken when essential. First, it must be understood that not all shorelines are at serious risk to significant erosion, as can be seen in Figure 5 (trunk vs. tributaries). Second, mitigation measures against shoreline erosion can have significant negative impacts on the immediate and adjacent coastal environments (e.g., neighbors and local fishing areas). Third, installation of hardened structures should really be undertaken as a last resort and not as an unnecessary preventative measure or for homeowner convenience.

If mitigation is needed, property owners should consult the web site of the Division of Coastal Management (DCM) and communicate with them to ensure that the recommended guidelines and laws are followed: http://dcm2.enr.state.nc.us/Hazards/estuarine.htm.

The following document can be used to understand what structures are recommended for different settings: http://dcm2.enr.state.nc.us/Hazards/EWG%20Final%20Report%20082106.pdf

Examples of various shoreline stabilization methods are presented here: http://dcm2.enr.state.nc.us/Hazards/estuarine_stabilization%20options.htm

Table 3. Shoreline stabilization methods outlined in August 2006 by the North Carolina Estuarine Biological and Physical Processes Working Group (http://dcm2.enr.state.nc.us/Hazards/EWG%20Final%20Report%20082106.pdf).

STRUCTURE TYPE	ALIASES	EROSION CONTROL PURPOSE
Land planning		Leaves the shorezone in its natural state.
Vegetation control	Wetland or upland plantings	Creates a buffer to dissipate energy.
Beach fill	Beach nourishment	Acts as a sacrificial erosive barrier.
Sills	Marsh sill, wooden breakwater, wave board	Reduce wave energy on the shoreline. Trap sediment landward to rebuild/ protect wetlands.
Groins	Jetties	Trap sand on the updrift side to build out the upland.
Breakwaters	Wave attenuator	Reduce wave energy on the shoreline. Trap sediment between the shore and breakwater.
Sloped structures	Riprap, revetment, sloped seawall	Protect land from erosion and absorb wave energy without reflecting waves.
Vertical structures	Bulkhead, seawall, gravity wall	Hold back the land.

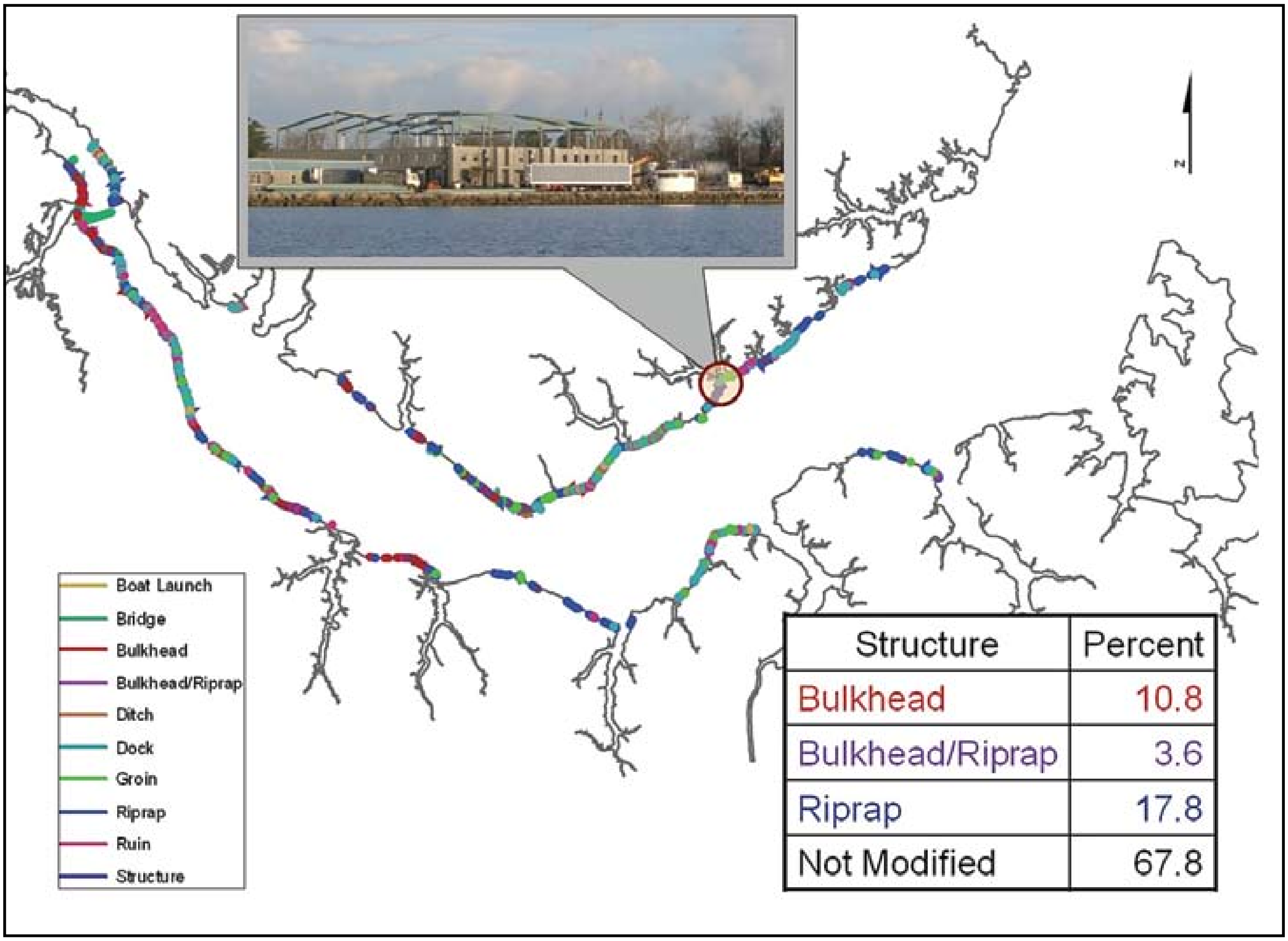

Figure 6. Modified shorelines along the trunk of the Neuse River Estuary in December 2007. The inset is an example of a shoreline stabilized with riprap along the Oriental waterfront.

SUMMARY

Erosion of estuarine shorelines is an ongoing and natural process within the northeastern North Carolina coastal system. Erosion rates are extremely variable, but the majority of the estuarine shorelines are currently eroding. This rapid and significant loss of land has led many property owners to use various stabilization methods to combat erosion. Little is known of either the short-term and long-term ecological impacts that these hard structures might have on the system, particularly if the processes of climate change and sea-level rise continue. To preserve our coastal estuarine resources and maximize human utilization, long-term management solutions to shoreline recession must be in harmony with the dynamics of the coastal system.

A digital version of this document, along with reports on related research funded by a grant from the University of North Carolina system, can be accessed at the North Carolina Coastal Hazards Decision Portal: http://www.coastal.geology.ecu.edu/NCCOHAZ/.

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BACK COVER PHOTOGRAPH. Tributary along the north shore of the Neuse River Estuary. Photo by Lisa Cowart

1907–2007
CENTENNIAL