DETERMINING THE SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF SEA-LEVEL RISE TO BOGUE BANKS, NC

by

Jeffrey Allenby

Dr. Michael Orbach, Advisor

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MP Advisor’s signature
Abstract

Over the next one hundred years climate change is expected to have far reaching impacts on coastal ecosystems, will influence the functioning of coastal processes, and affect the manmade infrastructure that has developed along the water. The four towns located on Bogue Banks, North Carolina are in a precarious position as the island’s topography is very close to the current sea level and they have a high amount of development. Due to a lack of clear guidelines, each town is currently approaching sea-level rise (SLR) based on its demographics and perceived risk, and consequently, none of the towns are fully addressing the effects that SLR will likely induce. By identifying the extent of SLR as well as policy areas that are lacking, this project is intended to act as a catalyst for the four communities on Bogue Banks to develop regulations and mitigation techniques that balance the environmental, economic and social implications of the available management strategies.

To better understand the implications of SLR on Bogue Banks, a geographic information system was used to model the effects on both the ocean and sound sides of the island. Determining the areas that will be at risk on the island will yield a variety of information that will be extremely pertinent to town and county planners as they develop regulations that attempt to adapt to and mitigate the effects of SLR.

Sea-level rise will have significant effects throughout Bogue Banks and each town will need to investigate and decide upon the best course of action based on local circumstances. The rapidly changing conditions along barrier islands and coastal areas will test the limits of existing rules and policy makers will have the substantial task of creating and modifying guidelines and regulations to govern how communities adapt to their new existence. In particular, policies pertaining to the issues of migrating wetlands, septic tank permitting, zoning of buildings, and transportation will likely need to be reconsidered if towns are going to successfully adapt to and mitigate the effects of higher sea levels.
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List of Acronyms

AEC - Area of Environmental Concern
CAMA - Coastal Area Management Act
CELP - Coastal & Estuarine Land Conservation Program
CHPP - Coastal Habitat Protection Plan
CRC - Coastal Resources Commission
CZMA - Coastal Zone Management Act
DCM - Division of Coastal Management (North Carolina)
DOT - Department of Transportation
DWQ - Division of Water Quality
FIRM - Flood Insurance Rate Map
IPCC - Intergovernmental Panel on Climate Change
LCGCC - Legislative Commission on Global Climate Change (North Carolina)
LUP - Land use plan
NCDENR - North Carolina Department of Environment and Natural Resources
NCFPMP - North Carolina Flood Plain Mapping Program
NFIP - National Flood Insurance Program
OEA - Ocean Erodible Area
PSDS - Program for the Study of Developed Shorelines
SFHA - Special Flood Hazard Area
SLR - Sea-level Rise
USCCSP - United States Climate Change Science Program
USACE - United States Army Corps of Engineers
Chapter 1: Introduction

All along the eastern seaboard, especially in the southeastern United States, there are wide coastal plains that are susceptible to even small changes in water level. Seasonal flooding and storm surges already inundate much of the coastline and can cause large-scale damage to human infrastructure, such as roads and houses. Furthermore, the land along the coast is continually being developed, placing more houses and more people in these high-risk areas.

The Intergovernmental Panel on Climate Change (IPCC) has stated that anthropogenic sources of greenhouse gases are causing an increase in global temperature, with an increase in sea level and more severe storms as likely effects of the increased temperature (IPCC 2007). In 2010, the North Carolina Department of Coastal Management (DCM) indicated that state agencies should start planning for between 0.38 and 1.4m (1.25-4.6ft) of sea-level rise (SLR) over the next century (NCDENR 2010). However, the final recommendations regarding the likely impacts and guidelines for developing local regulations to address SLR are still being produced.

Over the next one hundred years climate change is expected to have far reaching impacts on coastal ecosystems, will influence the functioning of coastal processes, and affect the manmade infrastructure that has developed along the water. While estimates of the extent of SLR can vary by location, the scientific community agrees that its impacts have already started to occur (IPCC 2007). The four towns located on Bogue Banks, North Carolina are in a precarious position as the island’s topography is very close to the current sea level and they have a high
amount of development. Due to a lack of clear guidelines, each town is currently approaching SLR based on its demographics and perceived risk, and consequently none of the towns are fully addressing the effects that SLR will likely induce.

Bogue Banks is about twenty-four miles long and home to around 7,000 permanent residents and as many as 80,000 seasonal residents. Erosion due to various coastal processes, such as longshore transport and SLR, reshapes the island’s geography continuously and the communities must decide between two main coastal property damage mitigation techniques: 1) ‘Hard’ and ‘soft’ engineering of the coastline; and 2) land-use planning (Godshalk et al. 1989).

Currently, the four communities on Bogue Banks are utilizing both strategies; beach nourishment to contend with shoreline retreat, and restricting development in high-risk areas. Current state regulations prohibit the use of hardened structures on the ocean side of the island, however they are allowed, and utilized, to protect sound-side properties. To guide development and reduce the impact to surrounding ecosystems, each town has created its own Coastal Area Management Act (CAMA) land use plan (LUP), which takes into account zoning, land suitability, and hazard/flood mitigation.

Despite the recent official stance DCM has taken, only three of the four communities on Bogue Banks mention sea-level rise (SLR) in their most recent CAMA LUP, and just one actually identifies the general effects that SLR may have on

1 Permanent and seasonal populations determined from individual town populations obtained from CAMA LUPs (Atlantic Beach 2006, Pine Knoll Shores 2008, Indian Beach 2006, Emerald Isle 2006)
the town. None of the current CAMA plans for the communities on Bogue Banks fully investigates or prepares for the potential impacts of SLR to the island, especially with regard to how infrastructure will be able to adapt to changing sea levels and how it might negatively affect the ecosystems on and surrounding the island. Before SLR inundates coastal areas, each community, as well as the state, will need to determine a firm and clear approach to managing its effects.

Proactively addressing the impacts of SLR can significantly reduce the environmental effects of poorly thought-out management decisions and result in considerable savings to the management agencies. By focusing on these issues before immediate change is required, each town can fully research its options and decide on a plan of action that is suited to its unique situation and provides the maximum amount of protection at the lowest cost. The purpose of this project is to identify and quantify the likely effects of SLR on Bogue Banks, and to act as a catalyst for the four communities to develop regulations and mitigation techniques that balance the environmental, economic and social implications of the available management strategies.

Figure 1: Four communities with CAMA Land Use Plans on Bogue Banks
Chapter 2: Sea-level rise predictions, modeling, and consequences

Sea-level rise basics and estimates

Global climate change is causing sea levels to rise around the world, with the warmer temperatures raising levels by expanding ocean water, melting glaciers, and possibly increasing the rate at which ice sheets discharge ice and water into the oceans (USCCSP 2009). While it is generally accepted that global SLR is occurring, there has been much debate about the rate at which sea level will rise in the next century based on different methodologies and incorporating different sources of water. Furthermore, local subsidence and glacial rebound of land can cause the relative rate of SLR to differ substantially within certain localities, making it difficult to determine the actual rate of change in any one place.

The IPCC, an international scientific advisory board tasked with quantifying the impacts of climate change, estimated that global sea levels will likely rise between 0.18 and 0.59m (0.59-1.94ft) by 2100 (IPCC 2007). However, this range of SLR was based only on thermal expansion and minimizes the input of water from land-based ice melt. While this projection likely underestimates the amount of SLR that will occur, the impact from thermal expansion has an extremely high likelihood of occurring and can be used as a minimum amount expected (IPCC 2007). Other estimates based on the IPCC methodology using recent increases in surface temperature to extrapolate the amount of thermal expansion came up with a revised estimate of 0.49 to 1.4m (1.64-4.6ft) (Rahmstorf et al. 2007). The Environmental Protection Agency (EPA) also estimates that ice discharges from Polar Regions could contribute an additional 0.2m (0.65 ft) of SLR if melting rates rise in conjunction
with global temperature and substantially higher levels of SLR if the rate of ice melt increases (EPA 2009).

Local increases in SLR are highly dependent on the geography of the area and can vary even between short distances. After studying land subsidence rates and tide gauges from around the state, DCM has determined that the state should start to prepare for between 0.38 and 1.4m (1.24-4.6ft) of SLR by 2100. While there will be local differences in SLR, DCM has created low (0.38m), medium (1m), and high (1.4m) scenarios of the increase in sea level over time based on the best scientific data available (NCDENR 2010).

![Figure 2: Low, Medium and High Sea Level Rise Scenarios (DCM 2010)](image)

There has been some concern expressed as to these estimates and how they relate to Bogue Banks (Rudolph 2011). While relative SLR along Bogue Banks might
be slightly lower than the state estimates, the data from the Atlantic Beach water-level gauge indicates that local SLR over the next century, extrapolated from historic data, could be within 9 and 15 inches assuming there is no change in the rate of SLR. Although this range is slightly lower than the range observed at the Duck station, used for the official estimates, the margin of error for the Atlantic Beach Station calls into question the validity of the measurements (Table 1).

Table 1: Mean Sea Level Trends for N.C. water-level stations (NCDENR 2010)

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Station Name</th>
<th>Mean Sea-Level Trend mm/yr</th>
<th>Mean Sea-Level Trend inches/century</th>
<th>Period of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>8651370</td>
<td>Duck</td>
<td>4.27 ± 0.74</td>
<td>16.8 ± 2.9</td>
<td>1978-2002</td>
</tr>
<tr>
<td>8654400</td>
<td>Cape Hatteras</td>
<td>3.46 ± 0.75</td>
<td>13.6 ± 3</td>
<td>1978-2002</td>
</tr>
<tr>
<td>8656483</td>
<td>Beaufort</td>
<td>3.20 ± 0.54</td>
<td>12.6 ± 2.2</td>
<td>1973-2002</td>
</tr>
<tr>
<td>8658120</td>
<td>Wilmington</td>
<td>2.12 ± 0.23</td>
<td>8.4 ± 0.8</td>
<td>1978-2002</td>
</tr>
<tr>
<td>8659084</td>
<td>Southport</td>
<td>2.04 ± 0.25</td>
<td>8 ± 1</td>
<td>1933-1954, 1976-1988</td>
</tr>
<tr>
<td>8659182</td>
<td>Yaupon Beach</td>
<td>2.92 ± 0.77</td>
<td>11.5 ± 3</td>
<td>1977-1978, 1996-1997</td>
</tr>
</tbody>
</table>

Given these estimates, a change in sea level along Bogue Banks of between one and three feet is a reasonable approximation for the next century with a high likelihood of occurrence. For this study, the low, medium, and high DCM estimates were modeled to determine the relative impact to both the ocean and sound side of Bogue Banks.

**North Carolina and Bogue Banks Geography**

Low elevation and a gradual slope characterize the coastal counties of North Carolina, meaning areas far inland are potentially only a few feet above sea level. This low relief indicates that the area is extremely susceptible to changes in sea level and storm surge. Poulter and Halpin (2008) estimate that 5900 km² of land in
coastal North Carolina is susceptible to inundation with a 1.1m rise in sea level, around the middle estimate of SLR. However, the effect of tides and storm surge could drastically increase the amount of affected land. The gradual slope of the coastal plain in North Carolina has also allowed barrier islands to develop along the coastline and, over the past forty years, many of them have become highly developed.

These islands are extremely dynamic and have grown and changed many times in the past due to variations in sea level, storm climate, and other coastal processes. Typically, there are two types of barrier islands found off the coast of North Carolina; transgressive barrier islands, characterized by frequent overwash and landward migration, and regressive barrier islands, which have been building towards the ocean. Transgressive islands develop when sediment supply is less than the rate of relative SLR and are characterized by low elevation, shorter frontal dunes, large marshes on the estuarine side, and are typically thinner (Timmons et al. 2010). Regressive islands develop when the sediment supply exceeds the rate of relative SLR, causing the ocean shoreline to build seaward while the estuarine shoreline remains stable. This process results in islands with a higher relative elevation, tall frontal dunes, few marshes on the estuarine side and are typically wider (ibid.)

Bogue Banks, the island studied in this project, contains sections of both transgressive and regressive barrier morphology. Emerald Isle and Pine Knoll Shores are wide, up to 1.30 km; have high elevations, up to 13.25m above sea level; and contain a series of ridges and swales, characteristic of a regressive barrier.
Atlantic Beach, the eastern-most town, has a lower elevation, a discontinuous dune ridge, and extensive washover fans, characteristic of a transgressive barrier island. Indian Beach and Salter Path, in the middle of the island, appear to be near the threshold of transitioning from a regressive to a transgressive barrier island and have higher elevations and a single, tall frontal dune, however the island here is very narrow (~0.22km) (ibid.). Although parts of the island have historically been building seaward, the entire island is currently experiencing erosion on both the ocean and estuarine sides, causing a general narrowing of the island (Pilkey and Davis, 1987). It is believed that a reduction in sediment flow from rivers and inland areas as well as increasing SLR rates are the cause behind the net erosion rates on the island (Sallenger et al. 2007).

**Coastal retreat models and their criticisms**

As sea-level rises, there will be a corresponding amount of coastline retreat based on a variety of factors including elevation, slope, erodibility, and sediment composition. Furthermore, alongshore transport and other coastal processes affect local rates of erosion and accretion and are constantly reshaping shorelines in complex ways that are often hard to incorporate into coastal retreat models.

Historically, to determine the amount of erosion that will occur many coastal managers have utilized the Brunn Rule, which is based on the length and height of the active beach profile, or the area impacted by the effect of waves (Bruun 1962). The slope of the active beach profile, as well as the composition of the sediment under the barrier island, is believed to determine how much this rise in sea level will impact coastal erosion. On a managed shoreline, where the beaches are
nourished and little overwash occurs, the active profile starts at the top of the frontal dune and extends out to where the slope of the profile is equal to the slope of the continental shelf. Due to its protected location behind Cape Lookout, the active profile along Bogue Banks extends about 900m offshore to a depth of around 12m (Hine and Snyder 1986). The shape of this profile is in equilibrium based on the water depth and as sea-level rises, the profile will shift upwards and landwards using eroded sediment from the land to raise the profile (Figure 3) (Bruun 1962).

By itself this model is overly simplified and does not take into account a number of other factors that can significantly impact the amount of retreat that will occur (Cooper and Pilkey 2004). While the general concepts behind the model are fairly well agreed upon, opponents of mathematical models argue that the preconditions required will rarely occur naturally, rendering the outputs not valid. In a 2000 paper, a group of scientists elaborated on the major criticisms of mathematical models of coastline retreat listing a number of conditions that make most models incomplete (Thieler et al 2000). The model presented in this paper is meant for the academic purpose of showing the possible implications of sea-level
rise and is not intended to be used for planning purposes or to delimit the actual extent that will be affected by sea-level rise. Nonetheless, it is important to note that many of the criticisms raised regarding mathematical models have a minimal impact within the study area, indicating that the affected areas, especially on the sound side, should be a fairly accurate representation of future conditions if current beach management practices remain constant.

One of the major criticisms of the Bruun Rule is that it assumes that there is no loss of sand from the system, which rarely, if ever, occurs in nature. Typically sand exits the nearshore system through three processes: longshore transport, offshore transport through processes such as turbidity currents, and overwash through either storm surges or aeolian transport. On Bogue Banks, longshore currents move sand from west to east at a rate of about 22,500 m³/yr, eventually depositing sand into Beaufort Inlet (USACE 2008). As the inlet is regularly dredged, with the sand being placed back onto the island, longshore transport may represent a small loss to the western towns, however research has shown that the effect of longshore transport is minimal along Bogue Banks (Reed and Wells 2000). In comparison, nourishment projects in each of the towns on the island regularly place between 30,000 and 1,000,000 m³/yr on the beaches, indicating that the amount of longshore transport occurring is minimal compared to the sand being placed on the island (PSDS 2010).

Sediment samples taken offshore off Bogue Banks indicate that modern shoreface sediment was only found to a certain depth, about 12m, and only a small portion of sediment that is characteristic of nourishment sand reaches this point
(Hine and Snyder 1986). While the study does not claim there is no offshore transport, it appears that generally after about 12m there is minimal movement of sediment indicating the presence of an effective base of the shoreface.

The topography of Bogue Banks also greatly influences the amount of overwash the island experiences. As much of the island is classified as a regressive barrier, the majority of the island rarely experiences overwash due to its high frontal dunes and, consequently, minimal sand resources are lost through this process (Timmons et al. 2010). Although Atlantic Beach is classified as a transgressive barrier island, and occasionally experiences overwash, this part of the island also experiences the greatest volume and most frequent application of nourished sand, counteracting the amount of sand that is lost through any overwash that might occur.

Another common criticism is that the Bruun Rule does not take into account the sediment composition of the island that is being eroded. As fine sediment will not stay in the active beach profile, islands with a low proportion of beach grade sand will require more erosion to balance the profile slope. While this could theoretically create a large difference in the amount of retreat experienced, recent research has shown that the effect of substrate composition has a minimal influence on the amount of retreat (Moore et al 2010). Furthermore, as the island has a history of building towards the ocean, much of the substrate is composed of beach material that, when eroded, will stay within the nearshore system (Hine and Snyder 1985). Additional research has shown that sand deposits under the island extend at least 10m deep, the depth of the base of the profile, indicating that there is sufficient...
sand that can be mobilized to rebalance the active beach profile (Steele 1980).

In many cases, the amount of erosion due to SLR is less than the other erosional forces acting on the island. DCM calculates erosion rates along North Carolina’s coasts regularly by comparing the location of the coast based on historic aerial imagery. As these erosion rates are based on historic and present locations of the shoreline, they take into account nourishment projects that are intended to keep the shoreline stationary. Some retreat analyses utilize current erosion rates to extrapolate future coastline position in the future, however this method relies on a static erosion rate and does not incorporate changes in coastal processes or storm climate that could significantly impact local erosion rates (Honeycutt et al 2001). To obtain more accurate retreat rates, the multiple sources can be combined to calculate net erosion rates that balance retreat from sea-level rise with existing erosion, or accretion, rates.

**Consequences of Sea-level rise in Coastal Ecosystems**

There are a number of potential consequences of SLR that will impact barrier island ecosystems and infrastructure as sea level rises. The effects that will likely have the greatest immediate impact are erosion and inundation of the islands. As described above, and seen throughout the state already in areas such as Rodanthe and Wrightsville Beach, ocean-front erosion will cause the first row of houses to be located in an area that is increasingly unstable. Consequently, the possibility of having to relocate or abandon the structures for safety reasons will increase as SLR increases. As SLR and erosion decrease the height and width of the frontal dune system, the entire island will be at an increased risk of overwash and flooding
during extreme weather events, such as hurricanes and Nor’easters, putting a much larger number of structures in danger.

Inundation on the sound side of the islands will also have far-reaching effects as this land is typically at a low elevation and threatened by even small changes in sea level. This land is typically marsh, which has some ability to vertically accrete in conjunction with SLR, however this is dependent on the rate of sea-level rise and the amount of sediment available. If there is a reduced sediment supply, as is the case on a regressive barrier, the edge of the marsh will likely erode to supply the necessary sediment (Mattheus et al 2010). While the fate of marshes is highly dependent on these processes, upland areas that are currently dry land have the potential to be converted to wetlands as they are regularly inundated by spring tides.

The impacts to coastal communities and infrastructure from SLR extend beyond erosion and inundation. Beaches, dunes and wetlands all provide natural flood protection for the coast, buffering the effects of storms and abnormally high tides. As sea-level rises, transgressive barrier islands and beaches migrate landward as storms push sediment-laden water over the frontal dunes naturally nourishing the island and allowing it to maintain its height and its width (Fischer 1986). Bogue Banks, however, does not experience overwash on much of the island. Without this sediment supply allowing marshes to accrete, many of the back-barrier ecosystems will be at an increased risk of drowning. Without these natural systems in place, large storms will have a much greater impact farther inland and will cause damage to infrastructure and houses along both sides of the island (Fischer 1986).
Flooding and degradation of septic tanks and sewage systems are one of the largest risks to coastal ecosystems (Deyle et al. 2007). As the water table rises and flooding occurs more frequently, metal pipes and tanks will corrode and plastic pipes will float causing cracking and the release of raw sewage. Furthermore, settling and subsidence of previously dry soil will cause pipes to crack requiring a substantial amount of maintenance (ibid). Septic tanks also require certain soil conditions to function properly. The entirety of Bogue Banks is considered to have “poor quality” soil for septic tanks, due to slope, soil consistency, or flooding; however, the entire island currently relies on either septic tanks, or larger package treatment plants, for wastewater treatment without incident. A rising water table may cause a large number of these tanks to cease functioning properly, allowing untreated sewage to flow into the surrounding waters contaminating marsh and estuarine ecosystems.

Any rise in sea level would also have large-scale ramifications for both land and water transportation. Low-lying roads near the coast would have to be protected and elevated as the risk of flooding increases. Inundation of the substrate of many roads may cause cracking and require increased spending to repair and maintain usable roads. As sea-level rises, the clearance of bridges will decrease, which subjects them to greater amounts of salt spray, speeding corrosion, and will cause difficulty in navigation for low clearance bridges (ibid). The North Carolina Department of Transportation has also warned that existing drainage systems may not continue to function properly as sea-level rises, making some roads impassable during extremely high tides, during storms, or after heavy rains. (NCDOT 2010).
Chapter 3: Coastal Legislation and Regulatory Agencies

Federal Legislation

The Coastal Zone Management Act (CZMA), passed in 1972, was written after federal and state governments began to realize the impact that development and other human activity was having on fragile coastal ecosystems. This act provides states with federal funding and guidelines to develop individualized coastal zone management plans that balance economic development with environmental protection. The CZMA has been effective in many states because it allows the state to tailor policies to its unique issues, ecology, and geography (Kalo et al. 2007).

Within the CZMA, as amended in 1992, the act identifies SLR as a potential coastal hazard and instructs states to plan accordingly “(l) Because global warming may result in a substantial sea-level rise with serious adverse effects in the coastal zone” (CZMA 1972a). Section 303 delves further into the issue and declares the national policy of

(2)(C) the management of coastal development to minimize the loss of life and property caused by improper development in flood-prone, storm surge, geological hazard, and erosion-prone areas and in areas likely to be affected by or vulnerable to sea-level rise, land subsidence, and saltwater intrusion, and by the destruction of natural protective features such as beaches, dunes, wetlands, and barrier islands…(CZMA 1972b)

However many states, including North Carolina, do not stress this mandate in their implementation of the CZMA and clear recommendations of how to prepare for SLR are not addressed.

The National Flood Insurance Program (NFIP) is a federally funded program that provides flood insurance to property owners who live in participating
communities and is “designed to provide an insurance alternative to disaster assistance to meet the escalating costs of repairing damage to buildings and their contents caused by floods” (FEMA 2010). As part of this program, Flood Insurance Rate Maps (FIRMs) are created illustrating areas vulnerable to various flood risks. Communities are required to create floodplain management ordinances based on the FIRMs to reduce future flood risks to new construction. In many cases, financing for the purchase of new homes is contingent on the purchase of flood insurance under this program, and the designation of a property as “at-risk” can have substantial implications for interest rates and loan terms.

Except for Emerald Isle, the majority of Bogue Banks is considered to be “at-risk” to a 500-year flood and large portions are considered to be in the Special Flood Hazard Area (SFHA), which requires flood insurance (NCFPMP 2011). Rising sea levels will cause an increased portion of the island to fall in the SFHA zone requiring a number of property owners to purchase flood insurance and comply with all local floodplain management ordinances.

**State Legislation**

Within North Carolina there are a number of policies that regulate the various aspects of coastal development. The Coastal Area Management Act was created to fulfill the state requirements of the CZMA and was passed by the state General Assembly in 1974 and approved by the federal government in 1978. CAMA established the Coastal Resource Commission, a fifteen-member board responsible for creating management guidelines and regulations for North Carolina’s twenty coastal counties, and the Coastal Resource Advisory Council, a 45-member scientific
advisory board that provides technical expertise for the CRC representing a wide variety of specialties and sectors. Within CAMA, the responsibility of creating land use plans is divided by county, although municipalities are allowed to develop a LUP to manage their jurisdiction as long as it is approved by the state. Each of the incorporated towns on Bogue Banks has taken advantage of this provision and has created a CAMA land use plan adapted to the demographics, natural systems, and geography within their jurisdiction. While the LUP Technical Manual created by the CRC for developing land use plans includes sea-level rise as a coastal hazard, there are no specific guidelines describing how counties or municipalities should incorporate SLR planning in the LUP. Consequently, SLR is typically briefly mentioned but rarely addressed within the final CAMA LUP.

The Coastal Habitat Protection Plan (CHPP) was created as a result of the Fisheries Reform Act in 1997 and requires the Marine Fisheries Commission, the Environmental Management Commission, and CRC to work together to identify and protect coastal habitat areas and improve the effectiveness of current programs protecting fish habitats (Street et al 2005). Within the CHPP, sea-level rise is recognized as one of the four major threat classes to coastal systems and is addressed at length in each of the habitat types as a “threat and management need.” Some of the specific threats related to development on Bogue Banks that are identified in the CHPP include the upland migration of coastal wetlands, the erosion of coastal and estuarine shorelines, and the potential ecological impacts of continued beach nourishment (Deaton et al 2010).
North Carolina Regulatory Agencies

The Division of Coastal Management, a division of the North Carolina Department of Environment and Natural Resources, works with the CRC to create and enforce policies regulating the permitting of coastal development. Of particular importance in controlling coastal development is the delineation of areas of environmental concern (AECs), ocean erodible areas (OEAs), and wetlands. DCM is also in charge of supporting CAMA LUP development, maintaining public beach and waterfront access, and administering the North Carolina Coastal Reserve system. DCM has been instrumental in monitoring coastal erosion and establishing setback lines for coastal development to protect structures from erosion. Finally, DCM is in charge of administering the Coastal & Estuarine Land Conservation Program (CELCP) within North Carolina, which utilizes federal and state funds to purchase land that will protect critical coastal and estuarine habitats (Price and Miller 2007).

Various other state agencies are in charge of systems on Bogue Banks that will likely be affected by SLR including septic tanks, storm water management, and roads (Miller 2010). All of the buildings on Bogue Banks utilize on-site sewage treatment systems, either single home septic tanks or multiple building package treatment plants. In Carteret County, publicly-owned central package systems are permitted by the Division of Water Quality (DWQ), while privately-owned package systems are permitted by the Division of Health Services. The Carteret County Health Department is in charge of permitting the construction, as well as monitoring the proper functioning, of private septic tanks (Carteret County 1999). As sea level rises and the water table increases, these systems will be jeopardized potentially
allowing raw sewage and excess nutrients to contaminate adjacent waterways.

Storm water management is another concern for the towns on Bogue Banks. There are already areas within each of the communities that experience ponding in low-lying areas during heavy rain events. As sea levels rises, many of the passive storm water systems, which rely on gravity to drain areas through culverts and drainage pipes, will cease to function creating large problems on the island. DWQ is responsible for monitoring storm water runoff in the state however the local communities will have to decide how to effectively manage flooded areas. The NC Department of Transportation (DOT) may also be concerned with storm water management as it could potentially impact the functioning, or even existence, of roadways. Flooding, as well as destabilization of the ground under roads, is a major concern for the DOT as an expected impact of SLR. Clearance under the bridges connecting Bogue Banks to the mainland is another potential impact that is starting to be addressed (Devens 2010).

In May 2010, the NC Legislative Commission on Global Climate Change reported to the NC General Assembly the results of a four-year study determining the likely outcomes of climate change in North Carolina. The study identified a number of effects likely to occur within the coastal zone and encourages local governments to start consider the impacts of wetland migration, establishing a permitting system for hardening estuarine shorelines, and how they will adapt to potential changes in tax revenue based on projected increases in sea level over the next century (LCGCC 2010).
Chapter 4: Demographics, Geography, and CAMA Land Use Plans

The demographics and geography of each of the four towns on Bogue Banks varies substantially and results in different interpretations of the perceived risks of sea-level rise. These differences are reflected in how each town addresses SLR in the four CAMA LUPs that guide development on the island.

Emerald Isle

Emerald Isle is the largest community and is situated at the western edge of the island. With almost nine miles of beach front, 3,700 permanent residents and about 36,000 seasonal residents the town comprises about half of the population of Bogue Banks. The demographics of Emerald Isle indicate that the population is aging; the percentage of individuals over 65 rose from 14% to 22% in the last ten years, and contains a rising number of retirees (Emerald Isle 2006). The town is located on a part of the island that is considered regressive, historically building out into the ocean, and characterized by higher elevations. This barrier morphology lowers the risk of flooding but increases the risk of back-barrier erosion (Timmons et al 2010). Environmental conservation, especially protecting estuarine waters, maritime forests, and wetlands, has been a focus for land development in Emerald Isle and continues to direct zoning regulations in the town’s LUP (Emerald Isle 2006).

For the past twenty-six years the town has continuously dealt with beach erosion and inlet migration, mainly utilizing engineering approaches such as beach nourishment and inlet realignment to maintain the islands current geography. These projects are privately funded and are extremely costly (PSDS 2010). While
development in the inlet hazard area and ocean erodible area has stricter building codes, it is not restricted completely. This reliance on engineering as a mitigation strategy is reflected throughout the CAMA LUP allowing development, with building code restrictions, in almost all areas of the town except those that will affect wetlands and maritime forests. There is no mention of SLR within the LUP and none of the likely effects identified by DCM and other state agencies are addressed.

*Indian Beach*

Indian Beach is the smallest community on Bogue Banks with only 95 permanent and about 7,138 seasonal residents as of the 2000 census. The town is primarily a retirement and vacation community with 55% of the population over 55 years old and 97% of properties listed as seasonal homes (Indian Beach 2006). This portion of the island has experienced a varied geologic history and was previously as wide as Emerald Isle, but has since succumbed to sound-side erosion resulting in its current width (Timmons et al 2010). While the community north of Highway 58 is susceptible to flooding, the fore-dune region has a relatively high elevation significantly reducing the threat of SLR for a large portion of the town. Indian Beach is also unique on Bogue Banks in that 96% of its housing structures are either large condominiums (29%) or mobile homes (67%) (Indian Beach 2006).

Indian Beach recognizes the threat to the town from storms and erosion and has relied on federally funded engineering solutions to maintain the width of the beach and height of the dunes (PSDS 2010). There are building restrictions within current flood and erosion zones that limit the types of structures that can be erected, however the town plans to develop parcels regardless of their placement in
“at risk” areas. The town does recognize SLR as a hazard to the coastal system in their CAMA LUP and appears to be receptive to changes in zoning and building regulations, however the plan only addresses how the town would respond to SLR issues by allowing the construction of bulkheads on estuarine shorelines to prevent erosion.

_Pine Knoll Shores_

Pine Knoll Shores is the newest town on Bogue Banks and is regarded as a vacation and retirement community with almost two-thirds of its population over 55 years old. Incorporated in 1973, it is home to 1,524 permanent residents and 11,130 seasonal residents (Pine Knoll Shores 2008). Originally consisting of two Homeowner’s Associations, the town has always experienced well-guided development with an emphasis on residential development and environmental conservation. Pine Knoll Shores is located on one of the wider sections of Bogue Banks and shares the geologic characteristics of Emerald Isle, namely a high frontal dune and relatively higher elevations in the developed areas (Timmons et al 2010). To protect properties in the flood zone, the town government enforces strict state and county building regulations and has adopted a Hazard Mitigation Plan, which addresses the town’s response to multiple natural hazards. While Pine Knoll Shores relies primarily on beach nourishment to protect its oceanfront property, it also supports relocation as an erosion control measure. The town also acknowledges that SLR will impact its jurisdiction and has stated that it will continue to receive and review reports on SLR and revise town ordinances accordingly (Pine Knoll Shores 2008). Although this policy does not address specific hazards associated
with sea-level rise, it demonstrates that the town plans on using a combination of engineering and policy solutions to minimize the impacts of SLR within its jurisdiction (ibid).

*Atlantic Beach*

Atlantic Beach is the eastern most community on Bogue Banks and has the second largest population with 1,781 permanent residents and 25,620 seasonal residents. The town is younger, with only about a third of the population over 55, and not as affluent -- the median income was lower than the county average (Atlantic Beach 2006). Atlantic Beach is also the oldest town on Bogue Banks and has experienced large amounts of development in the past 130 years; much of it centered around the tourism industry. Approximately 26% of the town's acreage is coastal wetland, the conservation of which has been designated a priority for the community as it develops further. Bogue Banks near Atlantic Beach is lower in elevation, has a shorter frontal dune, and is more prone to storm surges, flooding, and ultimately beach erosion (Timmons et al 2010).

The town currently receives recurring beach nourishment from channel dredging into the port at Morehead City, which is regarded as the reason the town's actual erosion rate has remained so low (Atlantic Beach 2006). Atlantic Beach enforces all of the county and state building codes with regard to building in hazard areas, however it only restricts the development of sites if they will have a negative environmental impact. Due to its low-lying topography, Atlantic Beach dedicates a significant portion of its CAMA LUP to the potential impacts of SLR in the town and identifies areas that need to be addressed including transportation, wastewater
treatment, saltwater intrusion of aquifers, and flooding (Ibid). By far, Atlantic Beach has taken the most proactive approach with regards to identifying the implications of SLR, however the town has not enacted any regulations to minimize these effects.

Table 2: Comparison of the four incorporated towns on Bogue Banks

<table>
<thead>
<tr>
<th></th>
<th>Atlantic Beach</th>
<th>Pine Knoll Shores</th>
<th>Indian Beach</th>
<th>Emerald Isle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barrier Morphology</strong></td>
<td>Transgressive</td>
<td>Regressive</td>
<td>Regressive (Transitional)</td>
<td>Regressive</td>
</tr>
<tr>
<td><strong>Permanent Population</strong></td>
<td>1,781</td>
<td>1,524</td>
<td>95</td>
<td>3,700</td>
</tr>
<tr>
<td><strong>Seasonal Population</strong></td>
<td>25,620</td>
<td>11,130</td>
<td>7,138</td>
<td>36,000</td>
</tr>
<tr>
<td><strong>Susceptible to shoreline retreat</strong></td>
<td>No (Artificially)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Susceptible to estuarine inundation</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>CAMA LUP addresses SLR</strong></td>
<td>Yes</td>
<td>Yes (minimally)</td>
<td>Yes (minimally)</td>
<td>No</td>
</tr>
<tr>
<td><strong>CAMA LUP details effects of SLR to town</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>CAMA LUP details specific measures to address SLR</strong></td>
<td>No</td>
<td>No</td>
<td>Yes (minimally)</td>
<td>No</td>
</tr>
</tbody>
</table>
Chapter 5: GIS modeling of sea-level rise on Bogue Banks

*Basis for study*

To better understand the implications of SLR on Bogue Banks, a geographic information system was used to model the effects on both the ocean and sound sides of the island. Determining the areas that will be at risk on the island will yield a variety of information that will be extremely pertinent to town and county planners as they develop regulations that attempt to adapt to and mitigate the effects of SLR. This information includes determining areas that are at increased risk of erosion and inundation; the future extent of wetlands and likely areas into which they will migrate; and the potential loss in tax-base, acreage, and the number of homeowners affected in each town.

On the ocean side, the “future” coastline was estimated based on the position of the shoreline today with localized retreat rates calculated regularly along the shoreline that incorporate the amount of retreat expected according to the Bruun Rule in addition to DCM’s erosion rates. It is important to note that the coastline retreat model assumes that the major preconditions of the Bruun rule addressed in previous chapters are met and that beach nourishment efforts remain consistent with the current extent and volume placed on the shore.

On the sound side, the areas that will be continuously affected by SLR estimates were determined as well as the areas that will be regularly inundated by astronomical spring tides (1m above the new sea level). As discussed above, wetlands have the ability to vertically accrete, so the determination of “continuously inundated” land does not necessarily mean that this area will be underwater or lost,
but it will not be “developable.” Based on the fact that most of the land that is currently wetlands on Bogue Banks falls within the range of spring tides, it is likely that the land that is within this range with elevated sea levels has a high potential of being converted to wetlands, and consequently is determined to be “at risk” for this study.

By modeling the effects of SLR on the island, land use managers will hopefully have a better idea of the extent of the effect that SLR will have and be able to better visualize and proactively address the issues that will arise. Managers will also hopefully gain a better understanding of the potential extent of even small changes in sea level and how they will impact different barrier morphologies.

**Methodology**

The data used for this study was obtained through various county, state, and federal agencies and databases. High resolution LIDAR (Light Detection and Ranging) data was downloaded and compiled from the North Carolina Floodplain Mapping Program website and consisted of a series of Digital Flood Insurance Rate Map (DFIRM) panels containing 1/9 Arc Second (~6m resolution) elevation data for the entirety of Bogue Banks (NCFMP 2010). Bathymetry data was downloaded from the NOAA National Geophysical Data Center “GEODAS Grid Translator - Design-a-Grid” website utilizing a custom grid containing the study area and a significant portion of the adjacent offshore area (UL: 34.75°N, 77.166°W LR: 34.45°N, 76.62°W) (NOAA 2010). The location of the current shoreline, primary vegetation line, and annual erosion rate points were downloaded from the DCM website and subset to the length of shoreline along Bogue Banks (DCM 2010). To
aid in subsequent steps in the modeling process, the erosion point file was reorganized to ensure the points were sequential along the shoreline and the primary vegetation line was filled in for sections of the island for which it was not previously calculated. The Carteret County Shore Protection Office provided the Carteret County tax maps, which were subset to only include the properties on Bogue Banks.

Three main processes were involved with modeling the effects of SLR on Bogue Banks. The first process determined the seaward extent of the active beach profile, which was used later in the Bruun Rule calculations. The second process extracted data from the elevation, bathymetry, and active beach profile datasets to calculate the amount of retreat expected from the Bruun Rule in addition to the amount expected from existing erosion rates. The third process identified areas on the sound side of the island that would be affected by both inundation and high tides. The second and third processes were run for the DCM scenarios of 0.38m, 1m and 1.4m.

*Determining the Extent of the Active Beach Profile*

To determine the seaward edge of the active beach profile, the nearshore slope of each pixel in the bathymetry dataset was calculated by dividing the depth value by the distance from shore. As the base of the active beach profile represents the point where wave action no longer has an impact on sediment transport, identifying the area where the rate of change of the nearshore slope approaches zero can be used as a substitute for the base of the profile. Since the slope of a line represents the rate of change, the slope function of the Spatial Analyst extension of
ArcGIS 10.0 was used to determine the rate of change of the nearshore slope raster. This data was then reclassified with all values above 0.0015 as “1” and all values below 0.0015 as “NoData.” The areas classified as “1” were then converted to an unsimplified polygon and represents the extent of the active beach profile.

*Calculating the amount of shoreline retreat*

Once the coastal zone was determined, all of the necessary data for calculating the amount of coastline retreat according to the Bruun Rule was available. To determine the retreat rates along the coast of Bogue Banks, a custom iterative Python script was created to run through a series of processes for each DCM erosion control point along the island. This tool was designed to run in ArcGIS 10.0 and required user inputs specifying the input files for elevation, bathymetry, erosion control points, shoreline, and the primary vegetation line. The tool also requires values for the transect length to be used, the amount of SLR, and the time frame for the study. The coastal zone file was automatically imported from the previous step.

With all of the inputs specified, the tool loops through each point in the erosion control point dataset and calculates the angle of the shoreline between it and the adjacent point. It then casts two transects perpendicular to the shoreline; one with the specified transect length going out into the ocean and the second going 2000ft inland. The ocean transect was then clipped to the edge of the coastal zone and a point was generated at the end. The distance from the shoreline was calculated and the depth at this point was extracted from the bathymetry dataset. The inland transect was intersected with the primary dune line to create a point at
the top of the dune line, from which the distance from the shoreline was calculated and the elevation of the dune at this point was extracted. The amount of additional erosion due to existing processes was then calculated by multiplying the raw erosion rate, measured by DCM at each point, by the time period. Once all of this information was calculated, the retreat distance for that point could be calculated through the equation:

\[
\text{Retreat} = \frac{\text{Amount of SLR}}{\left( \frac{\text{Length of Ocean Transect} + \text{Length of Shore Transect}}{\text{Height of Dune} + |\text{Depth at Base of Active Profile}|} \right)} + \frac{\text{Amount of Existing Erosion}}{\text{Erosion}}
\]

After the amount of retreat at each point was determined, a point was generated along the inland transect at that distance. Finally, all of these retreat points were connected into a line that represents the new shoreline. A polygon representing the area lost between the existing and future shorelines was also generated to aid in determining the properties that will be affected by shoreline retreat.

*Calculating the amount of sound-side inundation*

To determine the amount of land that would be affected by sound-side inundation, a tool was built in ArcGIS to reclassify the elevation data at specific break points corresponding to the projected amount of SLR and the height of astronomical spring tides. Once the land within each inundation class was determined, the affected areas were converted to unsimplified polygons. To minimize the effect of anomalies of low elevation in the middle of the island, which would have a low likelihood of flooding due to SLR, polygons over 150m² were extracted to a new layer to be used in the determination of affected properties.

Once the ocean and sound side “at-risk” areas were determined for each of
the SLR scenarios, they were overlaid on the Carteret County tax maps. For the purpose of this study, properties that had at least half the parcel classified as “affected” were to be considered “at-risk.” A location-based selection was used to determine these parcels, with properties being classified as “at-risk” if their centroid was located within the boundaries of the affected areas determined in the previous steps. This process created a minimal amount of error by misclassifying some properties as unaffected despite a large majority of the parcel being classified as “affected” due to its centroid not being affected. The vast majority of properties, however, were classified properly and any grossly misclassified properties were manually corrected after the automated selection process had run.

Once the affected ocean and sound side properties were determined for each SLR scenario, the total tax value, acreage, and number of parcels affected was calculated for each town using the field statistics tool while dissolving the tax map layer based on the “city_limit” field. These values were then compared to the totals for the town in each of the three categories to determine the relative percentage of each town that was affected by each scenario. Maps were then created for each of the towns, with two for Emerald Isle, depicting both the extent of affected areas as well as the properties that will be affected by both inundation and coastline retreat.
Results and implications for each town

There are substantial differences in how the towns on Bogue Banks will be influenced by SLR in 2100 based, predictably, on barrier morphology and the amount of beach nourishment occurring in each town. While some of the towns had a consistent increase in the percentage of the community affected by each scenario, others appeared to have a threshold amount of SLR that the barrier could withstand, above which there was a drastic increase in the percentage of the acreage that was affected (Figure 4). Atlantic Beach and Emerald Isle appear to exhibit a threshold between 0.38m and 1m of SLR, possibly due to the increased rate of beach nourishment within these towns overcoming shoreline retreat, while Pine Knoll Shores appears to reach a threshold between 1 and 1.4m, likely due to estuarine inundation reaching the elevation of many properties within the town. Indian Beach and Salter Path do not seem to exhibit a threshold; instead the affected areas within the towns seem to increase linearly, which could be due to historic erosion along the backside of this section reducing the island’s ability to accommodate higher sea levels.

![Figure 4: Percentage of acreage affected by SLR in each town](image-url)
There also appears to be a threshold for the number of parcels and tax-value affected by each scenario, likely due to the at-risk areas extending beyond the first row of properties, either on the ocean or the sound, and impacting the more densely developed interior of the island. Atlantic Beach and Indian Beach demonstrate the largest changes between 0.38m and 1m of SLR, likely due to closely developed portions of the town lying only a few feet above sea level or close to the water (Figures 5-6). The other towns follow a more linear increase in the proportion of the town affected, possibly due to lower development density and higher elevations.
Low Scenario: 0.38m of SLR

The model of the low SLR scenario of 0.38m indicated that between 11-28% of parcels in each town would be affected by either coastline retreat or inundation (Table 2). Properties along the oceanfront and sound side of the island tend to be elongated, often including a substantial amount of wetlands and dunes, and typically contain a larger amount of acreage per parcel than the more tightly developed interior properties. As a result, SLR affected a higher percentage of each town’s acreage, ranging from 20-46%. The value of property along the oceanfront is higher than the sound side, slightly skewing the tax-value percentages to areas impacted primarily by coastline retreat. The total percentage of tax-value impacted in each town ranged from 12-39%. In general, the effects on the sound side had a more dramatic impact on the transgressive sections of the island, while the regressive sections experienced a greater impact from shoreline retreat.

Table 3: Tax-value, acreage, and parcels affected by 0.38m of SLR by town

<table>
<thead>
<tr>
<th>0.38m SLR</th>
<th>Tax Value</th>
<th>% of total</th>
<th>Acres</th>
<th>% of total</th>
<th>Parcels</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLANTIC BEACH</td>
<td>Ocean $3,763,602.00 0%</td>
<td>1.00 0%</td>
<td>10 0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sound $282,335,392.00 12%</td>
<td>633.21 43%</td>
<td>511 11%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total $286,098,994.00 32%</td>
<td>634.21 43%</td>
<td>521 11%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PINE KNOLL SHORES</td>
<td>Ocean $481,310,632.00 33%</td>
<td>155.02 13%</td>
<td>588 24%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sound $89,227,895.00 6%</td>
<td>409.40 33%</td>
<td>72 3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total $570,538,527.00 39%</td>
<td>564.42 46%</td>
<td>660 27%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SALTER PATH</td>
<td>Ocean $30,561,298.00 21%</td>
<td>30.54 27%</td>
<td>17 5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sound $12,891,834.00 9%</td>
<td>7.50 7%</td>
<td>26 8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total $43,453,132.00 29%</td>
<td>38.04 33%</td>
<td>43 14%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INDIAN BEACH</td>
<td>Ocean $206,931,629.00 33%</td>
<td>37.36 14%</td>
<td>301 24%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sound $23,779,744.00 4%</td>
<td>16.69 6%</td>
<td>53 4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total $230,711,373.00 37%</td>
<td>54.05 20%</td>
<td>354 28%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMERALD ISLE</td>
<td>Ocean $408,689,864.00 10%</td>
<td>534.60 18%</td>
<td>543 7%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sound $135,386,358.00 3%</td>
<td>460.62 16%</td>
<td>251 3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total $544,076,222.00 13%</td>
<td>995.22 34%</td>
<td>794 11%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Due to the amount of beach nourishment that it receives, Atlantic Beach had an extremely low percentage of properties affected on the ocean side of the island, however almost half the town’s acreage would be affected by inundation (Figure 7). The majority of the affected properties would experience temporary inundation from astronomic high tides, however this could have significant impacts for drainage and pooling as well as the functioning of septic tanks. While there would not be a large number of permanent effects, there would still be the potential of a $286 million drop in the towns tax-base and over 500 homeowners would theoretically have to vacate or significantly modify their properties and structures to accommodate the higher sea level.

Figure 7: Effects of 0.38m of SLR on Atlantic Beach
With a lower amount of beach nourishment, Pine Knoll Shores would have an increased rate of coastline retreat in addition to large portions of the backside of the island becoming regularly inundated (Figure 8). These impacts result in almost half of the town's acreage being affected in the 0.38m SLR scenario. The ridge and swale morphology of this section of barrier would allow water to penetrate into much of the Roosevelt Natural Area, impacting a large portion of the town's acreage and maritime forest. This area is not developed, however, and the percentage of parcels affected is considerably lower at 27%. Within developed areas, there are relatively few properties that will be affected by inundation. The higher percentage of oceanfront properties affected by coastline retreat results in almost 40% of the town's tax-value being impacted in the low scenario. To protect these properties, a considerable amount of additional beach nourishment will be needed.

Figure 8: Effects of 0.38m of SLR in Pine Knoll Shores
Lower amounts of nourishment along the beach fronting Indian Beach and Salter Path result in substantial shoreline retreat affecting approximately a quarter of the parcels in Indian Beach, but only about 5% of the properties in Salter Path (Figure 9). The regressive geologic history of this section of the island results in a higher elevation along the backside of the island, with few properties affected by inundation at 0.38m of SLR, most of which would only be periodically flooded. Due to smaller parcel sizes within the town, SLR will affect only 20% of Indian Beach’s acreage, representing 37% of its tax-value. Salter Path has slightly larger lot sizes in the affected areas with 33% of the total acreage and 29% of tax-value being affected. Increased amounts of beach nourishment will be needed to combat shoreline retreat in these towns, while little will need to be done to protect the sound side of the island in the low scenario.

Figure 9: Effects of 0.38m of SLR in Indian Beach and Salter Path
Having had substantial nourishment and inlet realignment projects, the effects of SLR are varied depending on location within Emerald Isle. The western edge of the town has experienced dramatic erosion as Bogue Inlet attempts to migrate eastward. The majority of the town, however, will not experience much shoreline retreat due to the amount of nourishment already occurring. The higher elevations within the town will also preclude many of the properties from the effects of sound side inundation (Figures 10-11). Only 11% of parcels, and 13% of tax-value, will be affected in the 0.38m SLR scenario. Due to elongated parcels along the sound side and a few large properties near Bogue Inlet, 34% of the acreage in the town will be experience some sort of impact from SLR. To combat these effects, Emerald Isle will need to slightly increase its current rate of beach nourishment as well as address the issue of wetland migration on the sound side of the island.

![Eastern Emerald Isle 0.38m of Sea Level Rise](image)

*Figure 10: Effects of 0.38m of SLR on Eastern Emerald Isle*
Moderate Scenario: 1m of SLR

The model of the moderate scenario of 1m of SLR indicates that the effect of SLR on Bogue Banks would increase substantially from 0.38m, with between 43-59% of the acreage in each town being affected by either coastline retreat or inundation (Table 3). The impacts also seem to extend into areas of higher development with between 23-71% of parcels being influenced and 30-69% of each town’s tax-value potentially affected. While oceanfront properties were primarily affected in the low scenario, a greater proportion of sound side properties are affected in the moderate scenario due to the low-lying nature of the island. In many
of the towns, the modeled shoreline has retreated almost to the primary vegetation line, meaning that the potential for overwash could increase dramatically and much of the island could be at risk to storm surges. Again, the effect of inundation was generally much greater in the transgressive sections of the island and the effect of coastline retreat was greater in the regressive sections. It also appears that areas that had previously experienced erosion, such as the sound side of Indian Beach, made adjacent areas more susceptible to inundation as the lower elevation swales became exposed to the estuarine waters.

Table 4: Tax value, acreage and parcels affected by 1m of SLR

<table>
<thead>
<tr>
<th>1m SLR</th>
<th>Ocean</th>
<th>% of total</th>
<th>Acres</th>
<th>% of total</th>
<th>Parcels</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
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<td>10%</td>
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<tr>
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The regular beach nourishment occurring in Atlantic Beach will continue to negate the shoreline retreat caused by 1m of SLR for much of the town, affecting only 3% of the parcels. Inundation, however, will influence 29% of the properties and almost 60% of the land in the town (Figure 12). In total, over a third of the town's tax-value will be affected, with the majority of this occurring on the backside of the island. All of the properties north of Highway 58, except for the far western portion of the town, will be affected by inundation with the high waters crossing the highway in some places. Potentially the most important consequence of 1m of SLR to the town is the regular flooding of the causeway to Morehead City, which could have drastic consequences during emergency situations or major storm events and would require substantial and costly improvements to raise this section of road.

Figure 12: Effects of 1m of SLR on Atlantic Beach
Shoreline retreat in Pine Knoll Shores will continue to affect the town severely; almost all of the properties located south of Highway 58 will be affected. This represents about 41% of the town’s tax value but only 14% of its acreage. The effect of inundation is still concentrated in the undeveloped Roosevelt Natural Area (Figure 13). Despite being 36% of the town’s acreage the flooded area would only include about 10% of the town’s parcels and tax-value. The conservation of this maritime forest has been designated as a priority, and will require the town to determine how it wishes to proceed, either protecting the land or allowing it to transition to wetlands. Again, only a small proportion of developed properties will be affected by inundation. In general, about half the town’s acreage and tax-value will be affected by 1m of SLR and slightly less than half the town’s property owners, 41%, will have to address the effects of SLR on their parcels.

Figure 13: Effects of 1m of SLR on Pine Knoll Shores
The amount of coastline retreat in Indian Beach and Salter Path would likely affect the entire first line of properties and extend to some of the second row parcels. Furthermore, the large multi-unit buildings containing a large portion of the towns’ parcels would be subject to the eroding beach, placing a large proportion of the town’s tax-value and properties in the at-risk zone. Inundation on the sound side of the island would also periodically flood many of the waterfront properties (Figure 14). Both towns had 49% of their acreage affected, but due to the presence of multi-unit buildings, mobile home parks and a higher building density, Indian Beach had a considerably higher percentage of tax value, 69% versus 49%, and parcels, 71% versus 37%, affected. Indian Beach, and Salter Path to a lesser extent, will have to invest a significant amount of money in increased beach nourishment projects to protect its properties from the movement of the shoreline.

Figure 14: Effect of 1m of SLR on Indian Beach and Salter Path
Despite the existing beach nourishment projects in Emerald Isle, 1m of SLR will cause a significant amount of shoreline retreat placing the majority of oceanfront properties at risk to shoreline retreat (Figures 15-16). Due to the high value of oceanfront properties, it is estimated that almost $1.3 billion worth of property would be affected in the 1m SLR scenario, representing 30% of the town's tax base. About a quarter of the town's parcels will be influenced by shoreline retreat or inundation and about 43% of the town's acreage will be at-risk. The effect of inundation is less than in other towns, only about 6% of properties, however the western tip of the island and the southern bank of Archer Creek will both experience considerable flooding. While Emerald Isle will not feel the effects of inundation as much as the other towns on the island, the town will have to expand upon its history of privately funding beach nourishment to offset the amount of expected retreat.

Figure 15: Effects of 1m of SLR on eastern Emerald Isle
High Scenario: 1.4m of SLR

The model of the high scenario of 1.4m of SLR indicates that the effect of SLR on Bogue Banks will affect an increased amount of land, between 49-79% of the acreage in each town, however the change in some towns was not as drastic as the change from 0.38m to 1m (Table 4). The interior of many of the towns is affected at this level causing more densely developed areas and higher percentages of parcels to be influenced, between 32-86%. With a complete removal of the front row and many second row parcels, except in Atlantic Beach, and significant sound side flooding, the tax-base for the towns will also be reduced by 41-88%. With the
exception of Atlantic Beach, the modeled shoreline has retreated to the primary vegetation line for most of the island, meaning that the barrier morphology threshold described by Timmons et al (2010) could be crossed and the entire island could transition to a transgressive barrier as overwash becomes more common. The likelihood of the barrier breaching at some points and inlets forming is also greatly increased where shoreline retreat and sound side inundation meet, particularly in the eastern portion of Emerald Isle, the western portion of Pine Knoll Shores, and near The Circle and in eastern Atlantic Beach. Highway 58, the main transportation route on the island, will also be affected by flooding and overwash in multiple places, creating a safety hazard and requiring substantial maintenance to ensure its remains passable. Much of the causeway in Atlantic Beach will also be permanently flooded at 1.4m of SLR, limiting access to the island.

Table 5: Tax Value, Acreage, and Parcels affected by 1.4m of SLR in each town

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<th>1.4m SLR</th>
<th>Ocean</th>
<th>% of total</th>
<th>Acres</th>
<th>% of total</th>
<th>Parcels</th>
<th>% of total</th>
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Two-thirds of Atlantic Beach will be regularly impacted by 1.4m of SLR, almost completely due to sound-side inundation. At this level, retreat from SLR is just beginning to negate the nourishment efforts and some oceanfront properties are affected (Figure 17). 44% of the properties in Atlantic Beach will be impacted, including a high number of interior properties. Similarly, 43% of the town's tax-base will be at-risk, however, the financial impact to the town could be much higher if the businesses along the causeway and Highway 58 were affected. While the percentage of properties affected does not change drastically from the moderate scenario, there is a considerable difference in the amount of land that that was previously only periodically inundated that will be permanently inundated in the high scenario. A number of places will also be prone to overwash and inlet formation when erosion and inundation are only separated by a short distance.

Figure 17: Effects of 1.4m of SLR on Atlantic Beach
Two-thirds of Pine Knoll Shores will also be affected in the high scenario. On the ocean side, the beach has eroded to Highway 58 through much of the town, and will impact every beachfront property (Figure 18). Consequently, 63% of the town’s tax-value will feel the effects of SLR and 55% of homeowners will have to modify their properties and structures to accommodate the higher water level. Although a large portion of this area is concentrated in the Roosevelt Natural area, which is almost completely flooded, portions of the previously unaffected, tightly developed, interior of the island will become periodically inundated. While the town may be able to counteract erosion through increased beach nourishment, the effect of inundation will be much harder to combat and will create large problems and costs for the affected properties.

Figure 18: Effect of 1.4m of SLR on Pine Knoll Shores
Indian Beach will sustain the largest percentage of properties, 86%, and tax value, 88%, affected by the high SLR scenario. Salter Path will fare slightly better, with 56% of parcels and 69% of tax-value falling within impacted areas (Figure 19). Both towns will experience dramatic beach erosion, however soundside inundation will also flood much of Indian Beach, including the large mobile-home parks. This inundation, as well as a number of large condominium buildings that will be at risk due to beach erosion extending past the structures, drastically increases the percentages of affected properties. The influence of SLR will be less dramatic in Salter Path as the interior of the island is at a higher elevation, making it less susceptible to inundation, and the majority of homes are set back from the beach. Both towns will need to invest heavily in increased beach nourishment and Indian Beach will need to decide how to protect soundside properties from flooding.

Figure 19: Effect of 1.4m of SLR on Indian Beach and Salter Path
Emerald Isle will experience the lowest percentage of properties affected in the high scenario, only 32%, due to its higher elevation and extensive nourishment projects. Erosion will affect the majority of first-row houses and multiple second-row parcels (Figure 20-21). The higher value of oceanfront property means that 41% of the town's tax-value will be impacted, while almost half of the town's acreage will be at-risk, primarily along the oceanfront and western end of the island. Erosion will move the shoreline back to the primary dune line through much of the town, extending past it in a few locations towards the eastern end of the town, which will increase the likelihood of overwash and, in the thinner portions of the island, increase the potential for inlet formation. The town will have to significantly increase the amount of beach nourishment to negate shoreline retreat, however the rest of the island will remain largely unaffected, including many soundfront homes.

Figure 20: Effect of 1.4m of SLR on eastern Emerald Isle
While each town will experience localized effects of SLR, there are some general trends that will occur island wide. Shoreline retreat will continue to be a problem for all of the towns, however it has a “proven” solution in beach nourishment. With increased amounts of retreat, however, each town will require a substantial amount of additional nourishment to maintain the position of the current shoreline. Although there are various tools utilized by coastal managers to estimate the volume of sand needed to balance the sediment budget, this project does not address these methods. Comparing the various amounts of shoreline retreat and nourishment efforts within the towns can, however, reveal rough trends of future nourishment needs. Emerald Isle’s nourishment efforts were overcome

Figure 21: Effect of 1.4m of SLR on western Emerald Isle
after 0.38m of SLR and Atlantic Beach’s frequent projects were effective at counteracting the retreat associated with 1m of SLR but were about even in the 1.4m of SLR scenario. Accordingly, the other towns on the island can expect to have to place sand on the beach at about the same frequency to counteract future shoreline retreat associated with the different SLR scenarios.
Chapter 6: Recommendations for Areas Needing Further Work

The existing regulations that govern coastal development have come a long way since their creation in the 1970’s and effectively protect a number of fragile ecosystems along our nation’s coast. The rapidly changing conditions along barrier islands and coastal areas will test the limits of these rules, however, as an ever growing proportion of the land will be impacted by rising sea-levels. In the near future, citizens and property owners will be faced with deciding between abandoning properties to natural processes, relying on increasingly expensive and environmentally damaging engineering solutions, or proactively addressing the issues and finding a balance between the two.

As coastal processes reshape barrier islands, policy makers will have the substantial task of creating and modifying guidelines and regulations to govern how communities adapt to their new existence. In particular, the issues of migrating wetlands, septic tank permitting, zoning of buildings, and transportation will likely be some of the largest changes that will impact Bogue Banks, as well as other barrier islands and coastal communities. Each of these policy areas is discussed to provide the basis for further consideration by the communities affected in an attempt to proactively address the issues and find solutions before the problems are physically impacting the island.

Wetlands

Migrating wetlands will likely present the largest regulatory gap that will need to be addressed in the near future as they will influence a number of other issues, particularly the zoning of other land uses. Wetlands are currently protected
under various federal, state, and local regulations, however the area adjacent to them is not. A likely issue regarding wetlands is the permitting of structures that fall within areas that are currently dry land, but have a high likelihood of turning into wetlands in the near future (EPA 2009). As wetlands migrate into upland areas, they will interact with existing structures, including houses and leach fields for septic tanks, which are permitted under current conditions. The future water level will create potentially hazardous conditions for both the population and the ecosystems on and around the island as structures are destabilized and raw sewage enters the water. Consequently, migrating wetlands will limit a property’s development potential and could affect the ability to obtain or maintain proper permitting for structures and wastewater treatment facilities. As seen in many beach erosion situations, legal issues will arise as public trust lands and protected ecosystems encroach on private land (Titus 1990).

Building hardened estuarine shorelines landward of any wetlands is allowed under current North Carolina regulations and will likely be increasingly utilized as the primary response to migrating wetlands on Bogue Banks. DCM has started to research the feasibility of regulating estuarine hardened shorelines, much like it does ocean shorelines, however the extent of estuarine shorelines within the state may make this a prohibitively complex task (Miller 2010). Furthermore, research has demonstrated that sand removed from estuarine systems and inlets for nourishment projects deprives existing wetlands of a necessary sediment source required to vertically accrete (Hackney and Cleary 1987). Limiting the migration of wetlands into upland areas while existing marshes are overcome by rising sea levels
will drastically limit their extent and have far-reaching consequences on the ecosystems surrounding Bogue Banks. As evidenced by their inclusion as a critical habitat in the CHPP, wetlands are an important nursery ground for more than 90% of North Carolina’s commercial and recreational seafood species; such as shrimp, flounder, and crabs; and a loss of this ecosystem could be severely detrimental to North Carolina’s coastal economy (Street et al. 2005).

DCM has acknowledged, in a draft SLR policy, that wetlands will migrate into upland areas, however the policy does not discuss the state’s actions to either protect coastal habitats or development (CRC 2011). There are three main directions that wetland migration policy can take:

- Preventing new development in sensitive upland areas;
- allowing development now and deferring any government action until sea level rise reaches a critical stage; or
- allowing development now, but with restrictions that would require the relocation of humanly constructed structures as sea level rises (Titus 1990).

As the state and local governments move forward with creating policy guidelines, they will have to decide on a balance between allowing properties to protect themselves against migrating wetlands, with large environmental and economic consequences, or forcing landowners to modify or remove structures that threaten these ecosystems as they move into upland areas, potentially raising legal issues and creating large environmental and economic impacts.

**Septic Tanks**

SLR will cause the water table under the island to rise, significantly impacting the proper functioning of septic tanks and multi-unit package treatment plants.
Both types of systems must acquire a series of permits prior to construction based, primarily, on existing soil conditions. As these conditions change due to SLR, a large number of the island’s properties may no longer be able to maintain a properly permitted system, requiring expensive improvements or the abandonment of properties (USEPA 2002). If septic tanks fail, large amounts of untreated waste would flow into Bogue Sound polluting the water and violating multiple state and federal regulations. Much of the estuarine waters surrounding Bogue Banks are already closed to shellfishing, however contamination from waste would also make it unsafe for boaters and other recreational uses. Harmful algae blooms, leading to hypoxic or anoxic conditions, could be another side effect of excess nutrients in the water (NCNERR 2007). Improper wastewater treatment could also pollute groundwater resources on which the island relies (Atlantic Beach 2006).

State and county governments will have to decide how to deal with the ongoing permitting of all existing and future septic tanks to ensure that they continue to function properly. This process would strain the resources of the county and state permitting offices, as it would likely require more frequent assessments of each property on the island to determine the ongoing effectiveness of each septic tank. Furthermore, due to the extent of “poor” soils on Bogue Banks, small changes in soil conditions could mean a prohibitively large number of properties within each town would lose their septic operating permits, spurring communities to petition for exceptions to be allowed. County and state governments will have to work with local governments to balance the interests of property owners with protecting the natural systems on and around the island.
**Building Codes**

Coastal infrastructure will also be threatened by rising sea levels. Oceanfront properties already have building codes to protect against storm surges and other extreme weather, however they are not as strict on the sound side. The effect of SLR on both sides of the island will require proactively adopting building regulations that accommodate higher sea levels and could cost property owners a considerable amount of money to upgrade existing infrastructure. The landward transition of coastal setback lines could also create a number of legal problems as existing buildings migrate into restricted areas.

The effect of storm surges, coupled with higher sea levels, will also have a more pronounced impact on the interior of the island, reaching properties farther inland than previously experienced. This will have serious consequences for FEMA floodplain maps and the ability of homeowners to obtain flood insurance. While most existing waterfront properties already incorporate design elements to protect against flooding, such as being placed on stilts, many interior houses that will be regularly affected by SLR, and storm surges, have no such protection.

DCM has already identified developing more stringent building codes for areas that will be impacted by SLR as a priority in its draft policy, however it is fairly ambiguous and “encourages new private [and public] development be designed and constructed to accommodate sea-level rise impacts within the structure’s design life” (CRC 2011). The Carteret County government opposes this policy, as long as it deviates from the “low” scenario, stating that the policy includes “very little thought to how it will impact the livelihoods of citizens and the economic fortunes of the
coast – development, tax bases, infrastructure, military operations and more” (Hogwood 2011). Currently, there are no official maps depicting the future extent of flooding within Carteret County, however the maps created for this project could serve as an initial estimate and help guide planning.

State and local regulations will need to be able to adapt to the conditions within each town and have the flexibility to address the specific risks that face oceanfront and soundfront properties because the impact of SLR varies so greatly based on location. Furthermore, the policies will need to balance the interests of the towns and homeowners, including their ability to obtain flood insurance and financing, with minimizing the vulnerability to SLR, increased storm surges, and flooding.

*Transportation*

The transportation systems on the island will face significant complications with a higher sea level. Some major roads, such as the causeway in Atlantic Beach and portions of Highway 58, will be regularly affected by SLR and will require substantial improvements to remain passable. These roads provide a number of important services within the communities, such as efficiently moving residents and visitors throughout the island, but most importantly they serve as the main conduits for emergency services and are the primary evacuation routes. If the roads are more easily flooded by extreme weather, evacuations will have to take place sooner, creating a higher potential for “false alarms,” which will in turn disrupt the tourism industry and the coastal economy (USGCRB 2009). For most of the communities the solution to this problem will entail raising the roads either by paving over the
existing roads or completely removing the road and rebuilding it after adding fill to the roadbed, both of which will be costly and require a significant time "out of service" (Titus 2002). Raising roads, as well as the decreased effectiveness of gravity-fed drainage systems, will result in an increased amount of standing water and flooding of properties.

The ability of roads and drainage systems to withstand higher sea levels will need to be addressed by county and state governments to ensure proper functioning. Transportation agencies will have to rethink the existing transportation systems and redesign a number of roads to ensure that they continue to function. State and county governments will also have to research new designs that will accommodate rising sea levels and authorize funding for the improvements. This will require a substantial increase in DOT's budget and each management authority will have to decide on priority projects that will receive funding and limited construction resources first.
Chapter 7: Conclusions

Governments at all levels are beginning to address the issues that SLR will create and investigate the possible responses. However, due to the ambiguity of the extent of the issue most are reluctant to create fixed recommendations until more definite information is available. Sea-level rise will have significant effects throughout Bogue Banks and each town will need to investigate and decide upon the best course of action based on the geography, demographics, and perceived risk within the community.

As the model demonstrates, shoreline retreat and estuarine inundation have the potential to cause dramatic losses on both sides of Bogue Banks. Each town will have a number of parcels impacted by SLR causing a number of problems for property owners. The economic implications for Bogue Banks calculated by the model indicate that SLR is a pertinent issue that will need to be addressed by each town if they want to remain financially stable. Even the low scenario shows a decrease of about $1.67 billion in the island’s tax-base, or about 8.6% of the county’s tax revenue (Carteret County 2010).

There are policy areas that will need to be addressed in the coming years that are common to all of the towns. Transportation issues will need to be addressed island wide in a coordinated manner, especially with regard to main thoroughfares such as Highway 58 and the causeways off the island. As the main regulator of septic tanks, the county will have to decide how to proceed with monitoring and permitting systems on the island while working with the towns and property
owners to resolve issues and investigate technologies that will continue to treat wastewater without a detrimental effect on the island’s ecosystems.

Each town will experience SLR differently and some policy areas will be more relevant than others. Atlantic Beach has transgressive barrier morphology and should be much more concerned with inundation flooding estuarine marshes and affecting properties on Bogue Sound. Consequently, migrating wetlands and septic tanks will be two key issues that the town will need to proactively address. Creating a policy framework that balances protecting fragile coastal ecosystems with the ability for residents to maintain their properties will allow Atlantic Beach to adapt to SLR with a minimal cost, both economically and ecologically.

Pine Knoll Shores is unique on the island in that it has large tracts of protected area, however, lower amounts of beach nourishment and low elevations in the Roosevelt Natural Area make the town susceptible to SLR on both sides of the barrier. There will be considerable costs associated with protecting threatened properties, however the tax-base potentially affected will likely drive the town to protect the shoreline in spite of the expense. The town will also need to decide if protecting the maritime forest in the Natural Area is a priority, which will provide increased resilience from severe weather, or if it should be allowed to transition to wetlands. Although most developed property on Bogue Sound and in the interior of the island is safe from even moderate amounts of SLR, Pine Knoll Shores will have to consider the implications of significantly increased beach nourishment efforts to protect oceanfront homes.

Indian Beach and Salter Path will both be significantly affected by shoreline
retreat in all three scenarios, however estuarine flooding does not become a
significant problem until the moderate scenario. Accordingly, the town will need to
initially focus on preparing for increased rates of beach nourishment and protecting
oceanfront homes. It should also begin to consider how to mitigate the effects of
rising sea levels on the sound side, however, as the moderate scenario will influence
a number of parcels that contain mobile homes and other large structures that will
not be able to adapt to SLR. Due to the uncertainty of the rate of SLR, the town
should focus on both sides of the barrier investigating the implications of increased
beach nourishment, migrating wetlands, septic tanks, and building regulations.
Proactively creating a policy framework that addresses SLR will allow both towns to
minimize the effects and reduce the costs associated with protecting properties.

Emerald Isle will likely experience the least amount of change from SLR due
to its elevation and regressive barrier morphology. Nevertheless, in the moderate
and high scenarios, the town will need to address coastline retreat as it impacts a
significant portion of the town’s oceanfront property and, in some places, threatens
to create inlets through the island. Sound-side inundation will affect a smaller
proportion of the community and, while it will be necessary to manage migrating
wetlands and septic tank functioning, compared to the eroding beaches and
migrating Bogue Inlet these processes will play a small role in the town’s
functioning. Emerald Isle has traditionally privately funded beach nourishment
projects, and as the need for nourishment increases, the town will need to research
the financial implications of increasing the frequency and extent of projects as well
as the availability of a sand supply large enough to fulfill the town’s needs.
Bogue Banks as a Whole

Due to its relatively high elevation, Bogue Banks will fare better than most other barrier islands along the North Carolina coast. The information presented in this paper demonstrates how different barrier morphologies react to SLR and will translate to other islands. Policy areas such as migrating wetlands, septic tank permitting, buildings’ ability to withstand higher sea-levels, and transportation infrastructure will need to be addressed in a well-thought-out manner that minimizes the cost to tax-payers and property owners while maximizing the ability of natural systems to continue to function properly. Although the rate of SLR is still being determined, the general consequences of a higher sea level will be the same regardless of the actual rate. This changes the fundamental question from “what are the implications of SLR?” to “what is the extent of the implications of SLR?” By shifting the focus, coastal communities will be able to develop policies that manage the general effects of SLR, allowing for the creation of adaptive response that can translate to any rate of SLR.

The towns on Bogue Banks are in the rare situation of having the time to fully investigate the implications of an issue before creating policies to manage its effects. Each community will benefit greatly from beginning to address the issues presented in this paper, as well as other issues that may arise, in the next few years as it will allow policies to be created that enable the towns and the ecosystems surrounding the island to thrive. Proactively addressing SLR will allow the four communities to develop regulations and mitigation techniques that balance the environmental, economic and social implications of the available management strategies.
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