Appendix G. North Carolina

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The coast of North Carolina has shifted significantly during the last few centuries due to rising sea level and other factors. In the 16th century the Outer Banks separated Roanoke Island (the first English Colony in North America) from the Atlantic Ocean, as they do today. But directly east of Roanoke Island was Roanoke Inlet, which separated Bodie Island (now southern Nags Head) from the barrier island to the north. There were several other inlets between Cape Hatteras and Back Bay. (Riggs and Ames, 2003 p. 118; Collet and Bayly 1790). Sediment transport along the shore eventually closed all of those inlets. Today, the nearest inlet is Oregon Inlet, more than 20 km away.

Other shores have also changed substantially over the last four centuries. Croatan Island was split by the creation of Hatteras Inlet, leaving its northern and southern portions connected to what are now Hatteras and Ocracoke Islands, respectively. Roanoke Island was connected to the mainland of Dare County until the early 19th century by marshes. When Roanoke Inlet closed, the currents that drain Albemarle Sound eroded channels through the connecting marshes allowing Albemarle Sound and Currituck Sound to drain to the ocean through Oregon Inlet and inlets farther south. (Riggs and Ames, 2003 p. 69). Stumpy Point Bay was an inland freshwater lake until the 19th century, when shoreline erosion opened it to Pamlico Sound. Albemarle-Pamlico Peninsula, which is very low and flat, at one time held the largest continuous area of wetlands in North Carolina and one of the largest in the nation (Cummings, 1966; Riggs and Ames, 2003 p. 69) but many of those wetlands have been drained for agriculture and other purposes.

The North Carolina coast continues to evolve. Many ocean shores are gradually retreating, claiming shorefront homes and prompting officials to relocate the coastal highway (NC-12) and the Cape Hatteras lighthouse inland.

This appendix examines some of the possible implications of rising sea level for North Carolina, with a focus on the impacts examined in chapters 1-6 of this report. The lands along North Carolina's Albemarle Sound, Pamlico Sound, and their tidal tributaries (sometimes collectively called the Albemarle-Pamlico Sound) account for 70 percent of the nontidal wetlands, 40 percent of the dry land, and 55 percent of all the land in the Mid-Atlantic within 1 meter above spring high water (Jones and Wang, 2008). Most importantly, the land is mostly low and wet. This area has a diverse array of habitats which include barrier beaches and salt marshes found in the rest of the Mid-Atlantic, as well as cypress and pocosin swamps (defined below) that are rarely found elsewhere in the region.

The extent to which these habitats can adapt to sea-level rise is unclear. The unique hydrology of the Albermarle-Pamlico Sound particularly the low tide ranges and low salinity, may make the area's habitats particularly vulnerable if changes in the barrier islands expose the sounds to higher tide ranges and higher salinity water. With more than 60 percent of the land within the Mid-Atlantic that might realistically be allowed to become submerged as sea level rises, North Carolina may represent an important environmental planning opportunity (Titus and Wang, 2008).

G.1 LAND VULNERABLE TO INUNDATION

The third largest area of land vulnerable to rising sea level in the United States lies between Cape Lookout and the mouth of Chesapeake Bay. In North Carolina alone, between 1300 and 1800 square kilometers of dry land is within one meter above the tides (See Chapter 1)[171] — approximately half the total for the entire Mid-Atlantic. Another 3000 to 3400 square kilometers of nontidal[172] wetlands are within one meter above the tides — again approximately half the total for the entire Mid-Atlantic. Three counties are almost entirely within three meters above the tides.

North Carolina's coastal zone can be divided into two different geological zones, each with different characteristics (Riggs and Ames, 2003). The zone northeast of a line drawn between Cape Lookout and Raleigh is called the Northern Coastal Province. It has gentle slopes, four major rivers, and long barrier islands with a moderately low sediment supply, compared to barrier islands worldwide. The rest of the state's coastal zone has steeper slopes, an even lower sediment supply, short barrier islands, and many inlets.

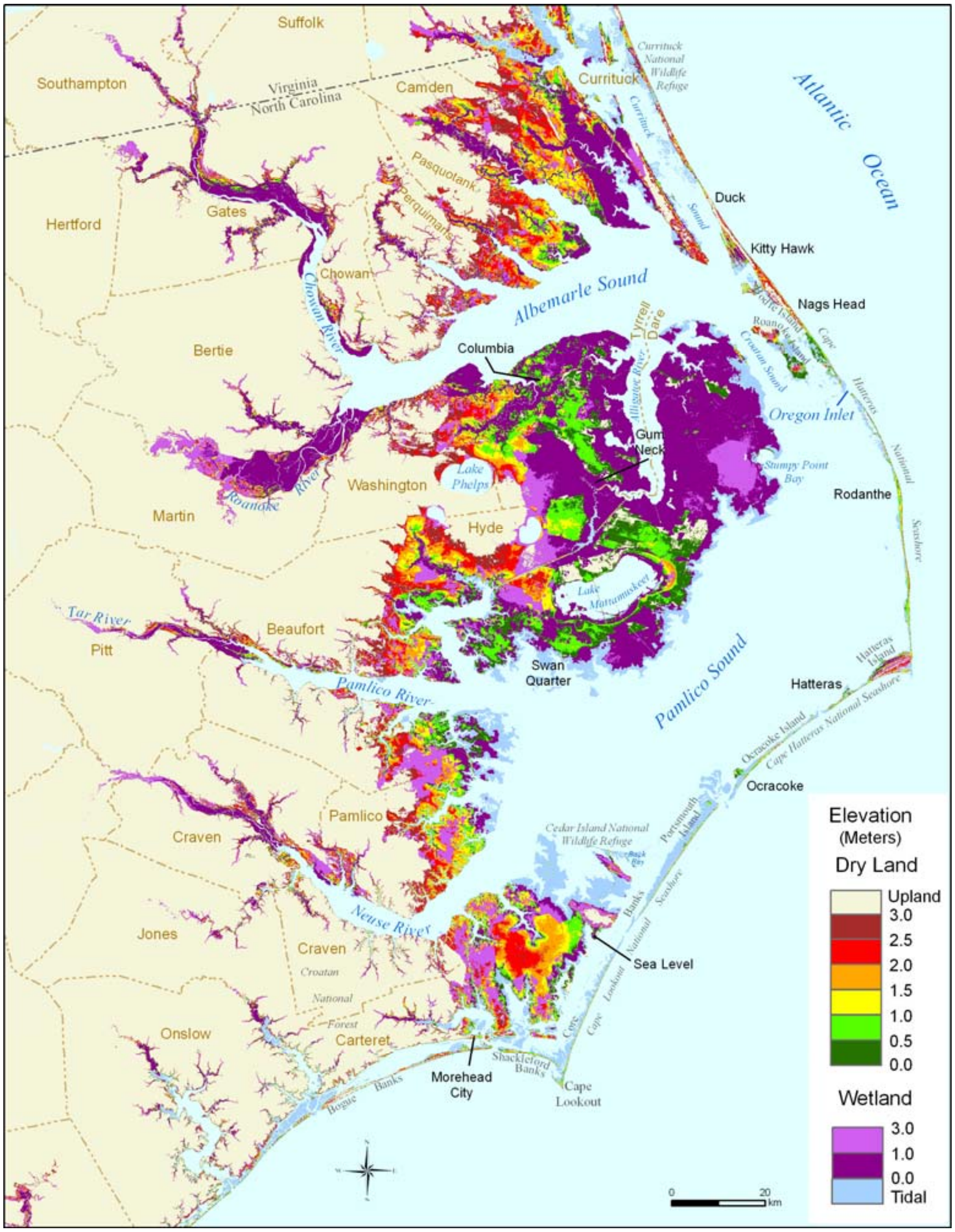


Figure G.1 Elevation of lands close to sea level: Cape Lookout to Virginia Beach.

Figures G.1 and G.2 show the elevations of lands close to sea level north and south of Cape Lookout, respectively, distinguishing between dry land and nontidal wetlands. Figure G.3 shows the northern portion of the coast, without distinguishing between dry land and wetlands[173]. Table G.1 provides low and high estimates of the area of dry and wet land, by county[174]. The entire state has between 700 and 1200 square kilometers of dry land within 50 cm above the tides, as well as approximately 2300 to 2900 square kilometers of nontidal wetlands. Hyde, Tyrrell, and Dare counties account for more than half of the nontidal wetlands within 50 cm of the tides (Titus and Wang, 2008; Titus and Cacela, 2008).

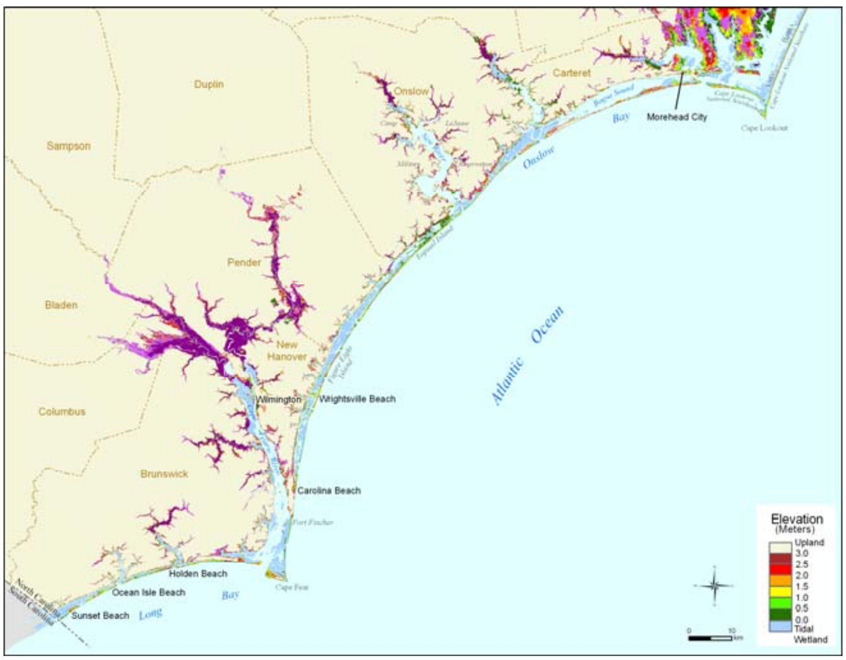


Figure G.2 Elevation of lands close to sea level: South Carolina border to Cape Lookout.

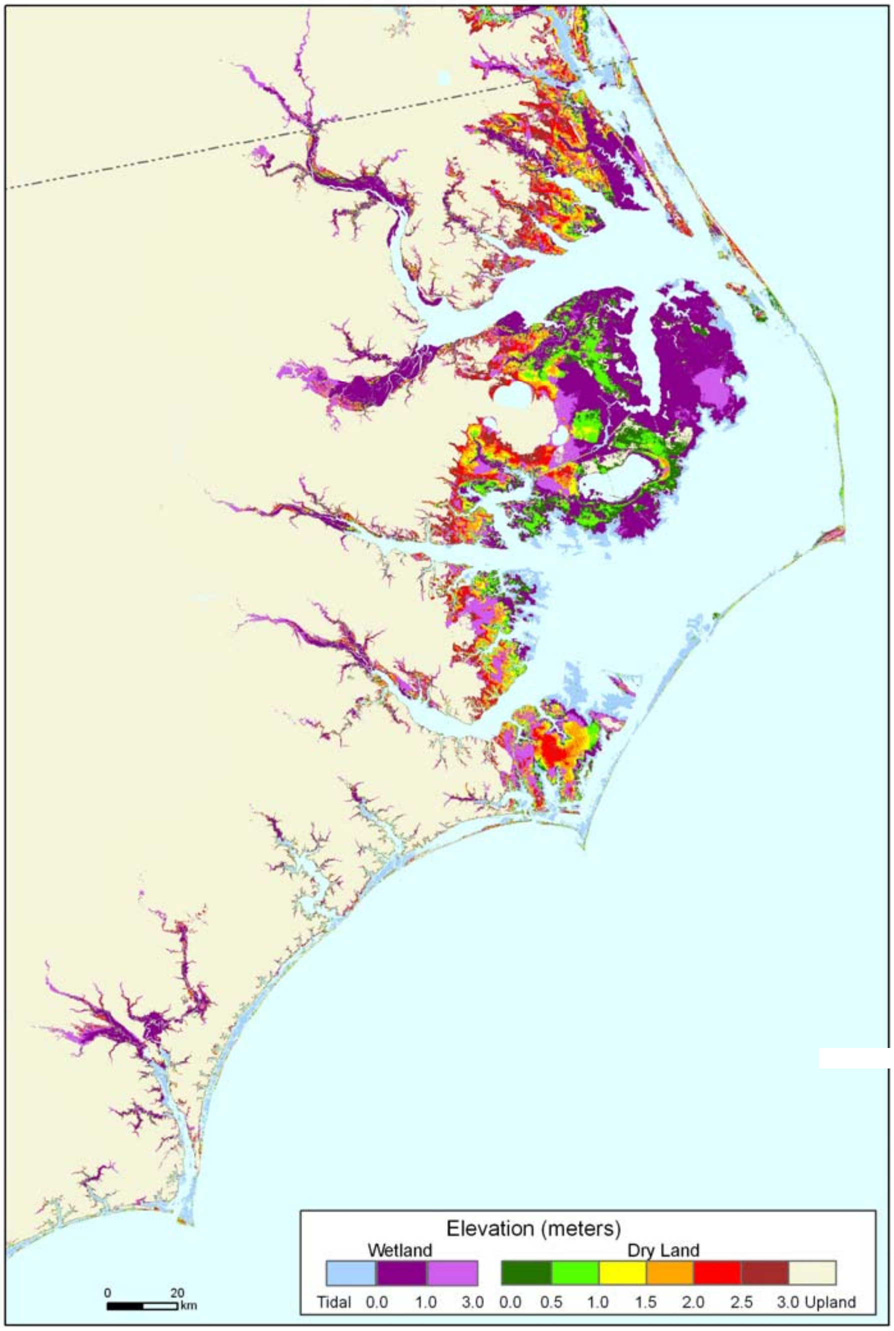


Figure G.3 Elevation of lands close to sea level: Cape Lookout to Virginia Beach.

Table G.1 Low and high estimates of the area of dry and wet land close to sea level (square kilometers).

	Tidal	50 centimeters		1 meter		2 meters		3 meters		5 meters	
		Low	High	Low	High	Low	High	Low	High	Low	High
County		Cumulative (total) amount of dry land below a given elevation									
Beaufort		48.6	93.1	109.4	156.4	257.2	317.2	422.2	481.8	722.2	744.0
Bertie		1.8	3.4	4.7	6.8	12.1	14.8	22.3	25.9	56.2	64.6
Brunswick		14.5	20.1	24.1	31.1	47.8	55.1	73.8	82.9	140.3	149.3
Camden		10.5	21.2	25.7	45.7	115.1	147.0	200.9	231.7	321.3	336.2
Carteret		56.0	95.5	126.9	179.4	326.4	379.3	427.4	436.8	489.9	495.5
Chowan		2.9	5.0	6.5	9.2	17.3	22.2	42.0	54.7	172.9	187.6
Craven		7.9	16.2	19.6	31.5	60.0	78.3	110.8	131.7	242.8	266.6
Currituck		22.9	37.9	49.6	70.6	143.4	177.8	251.7	273.3	321.7	325.5
Dare		47.0	65.2	71.5	86.1	106.2	117.5	133.4	140.4	153.7	154.8
Gates		5.3	10.5	11.3	16.1	22.3	27.1	36.3	49.6	106.6	130.2
Hertford		3.7	6.9	7.4	11.3	17.5	21.5	26.5	30.6	50.2	55.4
Hyde		280.5	410.4	433.5	482.0	548.3	586.4	640.9	659.5	703.9	707.4
New Hanover		8.3	13.0	14.9	20.5	29.9	35.1	45.2	52.0	83.5	89.6
Onslow		25.3	32.6	35.3	43.1	58.2	67.6	85.0	95.8	152.2	165.8
Pamlico		26.9	48.2	64.3	94.6	169.8	194.4	243.0	262.6	321.6	325.1
Pasquotank		11.0	26.1	39.6	64.9	131.4	161.2	220.7	259.4	457.3	460.0
Pender		5.9	9.9	11.6	16.8	28.0	36.3	55.2	68.9	135.9	148.6
Perquimans		5.0	8.8	11.7	18.1	51.9	79.1	144.7	189.4	427.1	432.0
Tyrrell		130.6	235.5	269.3	321.1	357.8	369.1	375.1	377.5	380.3	380.3
Washington		5.6	13.7	22.4	38.4	80.9	106.2	191.6	238.1	534.8	555.7
North Carolina[1]		**724**	**1179**	**1368**	**1757**	**2609**	**3030**	**3803**	**4208**	**6124**	**6349**
		Cumulative (total) amount of wetlands below a given elevation									
Beaufort	35.1	64.9	94.6	105.4	131.0	171.1	202.2	252.5	272.3	322.9	329.8
Bertie	0.3	110.2	123.1	127.0	132.4	146.9	152.6	171.0	176.9	224.8	233.6
Brunswick	109.2	38.4	44.0	47.2	51.9	60.8	64.6	73.2	76.7	94.6	97.8
Camden	7.1	137.2	146.3	148.7	154.6	167.7	174.7	186.8	194.2	243.1	258.0
Carteret	334.3	33.9	66.5	86.6	117.1	180.0	201.6	236.5	243.3	286.4	292.5
Chowan	0.0	29.1	32.5	34.0	36.6	41.7	43.9	51.2	55.8	95.9	104.3
Craven	12.1	58.9	74.3	79.7	94.4	121.1	136.8	158.7	169.7	216.6	227.5
Currituck	124.6	129.3	144.4	150.1	158.6	177.9	183.8	196.3	199.3	218.7	220.6
Dare	167.8	376.3	525.3	552.6	604.0	658.6	663.5	665.5	665.9	666.4	666.4
Gates	0.0	78.5	88.6	89.3	93.1	98.7	102.3	107.8	113.7	129.4	132.0
Hertford	0.0	44.8	53.0	53.8	57.6	61.8	65.4	68.9	70.8	79.7	81.2
Hyde	199.3	324.7	461.1	488.4	538.2	577.9	592.2	619.5	633.6	684.6	688.7
New Hanover	55.7	27.7	34.7	36.0	39.0	43.3	45.4	49.1	51.0	59.1	60.5
Onslow	68.8	24.7	29.6	31.1	35.1	41.3	44.7	50.5	54.0	69.4	71.7
Pamlico	111.6	51.6	66.7	73.1	81.0	106.3	123.1	148.4	161.0	221.1	231.6
Pasquotank	0.3	50.0	58.2	62.4	68.2	78.6	84.0	96.3	101.9	123.5	124.1
Pender	38.2	82.7	107.4	113.4	127.7	149.8	160.7	178.8	188.8	231.7	238.9
Perquimans	0.0	38.1	43.7	46.8	52.0	65.8	73.6	90.5	97.8	167.0	180.2
Tyrrell	3.8	421.7	502.3	522.5	554.1	571.5	578.9	593.3	601.5	622.5	622.5
Washington	0.3	70.0	78.2	85.5	92.5	105.5	112.0	134.5	145.5	191.8	197.1
North Carolina[1]	**1272**	**2280**	**2879**	**3048**	**3354**	**3794**	**3992**	**4347**	**4509**	**5273**	**5405**
Dry +		3004	4059	4415	5112	6404	7021	8150	8717	11397	11754

Nontidal wetland											
All Land	1272	4276	5331	5687	6384	7676	8293	9422	9989	12669	13026

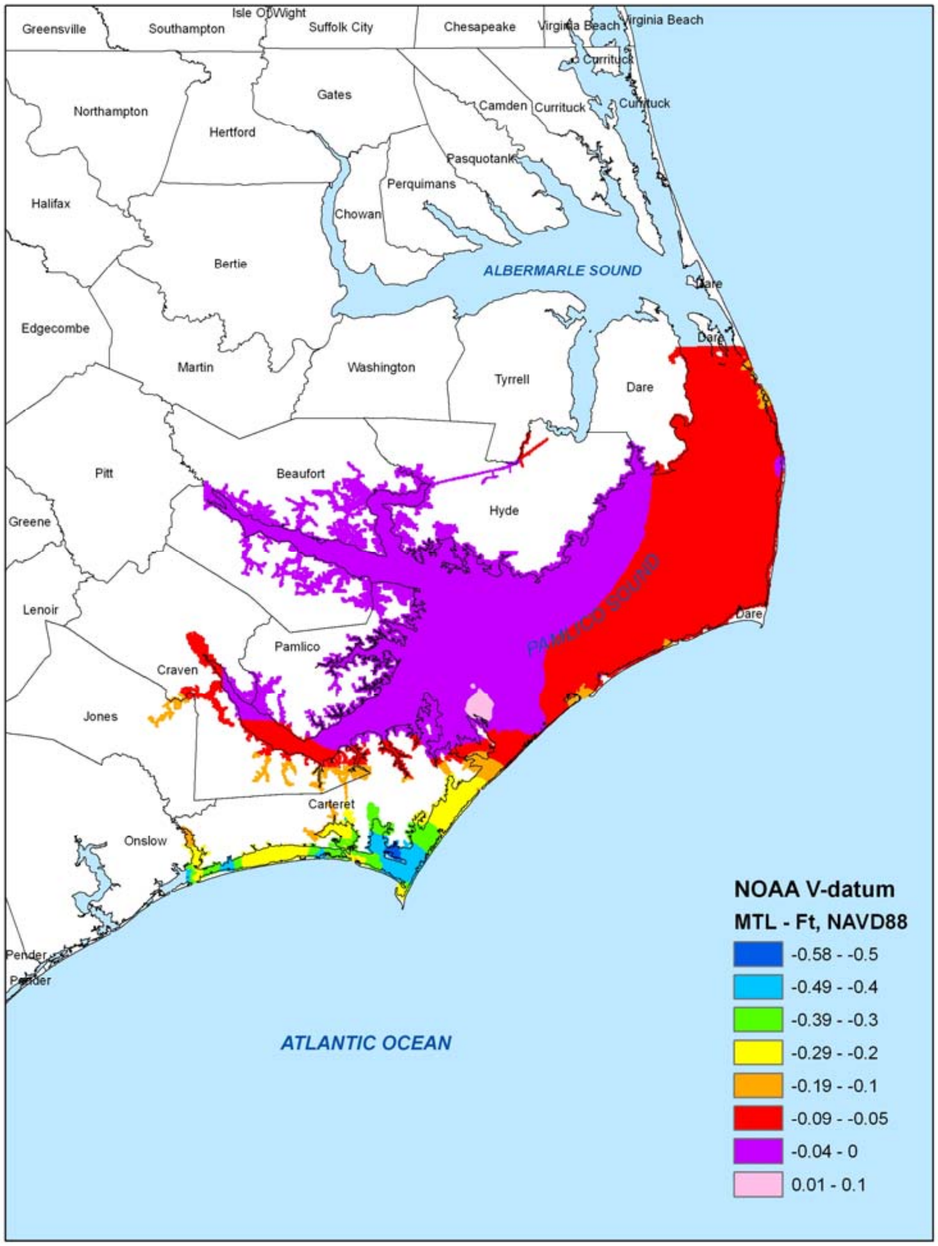
Source. Adapted from Titus and Wang (2008) and Titus and Cacela (2008) .
[1] Includes Bladen, Columbus, Duplin, Edgecombe, Greene, Halifax, Jones, Lenoir, Martin, Northampton, Pitt, and Sampson Counties which were omitted to fit table on a single page.

More than half the dry land below 50 cm is in either Hyde or Tyrrell County. But Carteret, Beaufort, and Dare counties also have approximately 50 to 100 square kilometers of dry land below the 50-cm contour. All of these counties have populated areas close to sea level. In the case of Dare County, some of the low-lying areas are on the sound side of the Outer Banks.

The data on coastal elevations probably understate the vulnerability of North Carolina relative to the rest of the Mid-Atlantic. Because the land is flat, areas a few meters above sea level drain slowly — so slowly that most of the lowest land is nontidal wetland. Because rising sea level decreases the average slope between nearby coastal areas and the sea, it may also slow the speed at which these areas drain. Some of the dry land a few meters above the tides could convert to wetland from even a small rise in sea level; and nontidal wetlands at these elevations would be saturated more of the time. Wetland loss could occur if dikes and drainage systems are built to prevent dry land from becoming wet.

The very low tide range in some of the sounds is another possible source of vulnerability. Albemarle Sound, Currituck Sound, and much of Pamlico Sound have a very small tide range, because inlets to the ocean are few and far between (NOAA, 2005). Some are narrow and shallow as well. Although Oregon and Ocracoke inlets are more than 10 meters deep (over 30 feet), the inlets are characterized by extensive shoals on both the ebb and flood sides, and the channels do not maintain depth for long distances before they break into shallower finger channels[175]. Like narrow channels, this configuration slows the flow of water between the ocean and sounds. Thus, although the astronomic tide range at the ocean entrances is approximately 90 cm, it decreases to 30 cm just inside the inlets, and a few centimeters in the centers of the estuaries.

The water-level variations are driven by local and regional wind and barometric pressure changes rather than astronomical tides. NOAA estimates that most of the estuary is about 15 cm above sea level (although the average water level in parts of these estuaries may be below the ocean sea level). Figure G.4 shows estimated mean tide level, compared with the reference elevation known as NAVD88, which is 13 cm above the ocean sea level (NOAA 2008). Therefore, even areas with no dikes have substantial dry land and nontidal wetlands within (for example) 30 cm above the estuary's mean tide level (45 cm above ocean sea level). But it is possible that rising sea level combined with storm-induced erosion will cause more, wider, and/or deeper inlets in the future (Zhang *et al.*, 2004; see chapter 2). If creation of more extensive inlets caused the astronomical tide range to increase to (for example) 60 cm, then the dryland and nontidal wetlands lands that are 30 cm above the estuary's mean level today would be inundated by the tides even if mean sea level did not rise[176]. For the same reason, if sea level continues to rise or accelerates, the average high tide could rise by 30-60 cm more than the rise in mean sea level.



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14024 **Figure G.4** Estimated Mean Tide Level in North Carolina Estuaries. Elevation compared with NAVD88.
14025 Source: Adapted from NOAA 2004.

The reduced tidal flushing also keeps salinity levels relatively low in most of the estuaries within the Northern Coastal Province (Riggs and Ames, 2003 p.9). Salinity is relatively high at the inlets, but declines as one proceeds upstream. Also, there is a strong seasonal variation with lower salinities during the periods of maximum river discharge and higher salinities during periods of drought. The salinity in Albemarle-Pamlico Sound can generally range from 0 parts per thousand (ppt) to 20 ppt, with the salinity in the upper reaches of the Neuse and Pamlico Rivers, Albemarle Sound and Currituck Sound having salinities usually below 5 ppt (Calwell, 2001; Tenore, 1972). Some tidal marshes (which are irregularly flooded by the winds rather than the regularly flooded by astronomical tides) are thus unable to tolerate salt water. In some areas, the flow of shallow groundwater to the sea is also fresh, so the soils are also unaccustomed to salt water.

More than other areas in the Mid-Atlantic, the Albemarle-Pamlico Sound region appears to be potentially vulnerable to the possibility that several impacts of sea-level rise might compound to produce an impact larger than the sum of the individual effects (Poulter and Halpin, 2008). If a major inlet opened, increasing the tide range and salinity levels, it is possible that some freshwater wetlands that are otherwise able to keep pace with rising sea level would be poisoned by excessive salinity and convert to open water. Similarly, if a pulse of salt water penetrated into the groundwater, sulfate reduction of the organic-rich soil and peat that underlays parts of the region could cause the land surfaces to subside (Portnoy and Giblin, 1997; Mitsch and Gosselink, 2000 p.10; Henman and Poulter, 2008).

Thus the land surrounding the Pamlico and Albemarle sounds faces the triple threat in which rising sea level (a) directly threatens low-lying areas with erosion and tidal inundation (Chapter 1) and might also create larger or more inlets (Chapter 3), which could (b) further increase tidal flooding, and (c) increase salinity levels, which could induce additional erosion and land subsidence[177]. Moreover, as we saw in Chapter 2, a substantial acceleration in the rate of sea-level rise could cause barrier islands to disintegrate. Pamlico Sound (and potentially Albemarle Sound) could be transformed from a protected estuary into a semi-open embayment with saltier waters, regular astronomical tides, and larger waves (Riggs, 2006).

G.2 SHORE PROCESSES

G.2.1 Ocean Coasts

North Carolina receives the highest wave energy along the entire east coast of the United States. When Hurricane Isabel cut a 1,700-foot-wide gap in Hatteras Island in September 2003, the North Carolina Department of Transportation and Army Corps of Engineers were able close the breach within two months at a cost of about $6.2 million (Schmitt, 2003; Beavers and Bruner, 2003). However, there are at least five sections of Hatteras Island that transportation planners refer to as “hot spots,” narrow, highly dynamic areas where the highway is at risk from storm surges at any time.

The North Carolina Division of Coastal Management (NCDCM) has calculated long-term erosion rates along the coastline adjacent to the ocean by comparing the location of shorelines in 1998 with the oldest available maps of shoreline location, mostly from the

1940s. The average erosion rate was 0.8 m (4.3 ft) per year. Approximately 18% of the ocean coastline retreated by more than 1.5 m/yr (5 ft/yr), and approximately 61% retreated by at least 0.6 m/yr (2 ft/yr). But 32% of the coastline accreted (NC DCM, 2003)[178]. The NCDCM recalculates long-term erosion rates about every five years to better track the dynamic shoreline trends and establish the setback line that determines where structures may be permitted on the oceanfront (NCDCM, 2005).

Several authors have estimated future shoreline erosion as sea level rises. One analysis of statewide erosion rates over the past 100 years led researchers to estimate that a one meter sea-level rise would cause the shore to retreat an average of 88 m, in addition to the erosion caused by other factors (excluding inlets) (Leatherman, Zhang and Douglas, 2000a)[179]. Another study estimated that a rise in sea level of 0.52 m between 1996 and 2050 would cause the shoreline at Nags Head to retreat between 33 and 43 m (Daniels, 1996).

Some researchers also believe that the barrier islands themselves may be in jeopardy if sea-level rise accelerates. According to Riggs and Ames, about 40 km (25 miles) of the Outer Banks are so sediment-starved that they are already in the process of "collapsing"[180]. Within a few decades, they estimate, portions of Cape Hatteras National Seashore could be destroyed by (1) sea-level rise (at current rates or higher), (2) storms of the magnitude experienced in the 1990s, or (3) one or more Category 4 or 5 hurricanes hitting the Outer Banks (Riggs and Ames, 2003). If several breaches were to open simultaneously, Pamlico Sound (and potentially Albemarle Sound) could be transformed from a protected estuary into a "semi-open embayment" with saltier waters, regular astronomical tides, and larger waves (Riggs, 2006).

Considering these and other studies, a panel of shoreline experts organized by USGS concluded that most of the Outer Banks between Nags Head and Ocracoke is vulnerable to barrier island disintegration over the next century if the rate of sea-level rise accelerates 2 mm/yr — and portions may be vulnerable even at the current trend. (See Chapter 3). The state of North Carolina alone has as much vulnerable ocean shore as all of the shores from Virginia to New York combined. (See Chapter 3).

G.3 VULNERABLE HABITATS AND SPECIES

Chapter 3 presents an assessment of the potential for wetland accretion from Virginia to New York, which excludes North Carolina. Nevertheless, authors in North Carolina appear to have reached a similar qualitative result. Some wetland systems are already at the limit of their ability to vertically keep pace with rising sea level, such as the remnants of the tidal marshes that connected Roanoke Island to the mainland of Dare County until the 19th century. The pocosin wetlands can vertically accrete by about 1-2 mm per year with or without rising sea level—when they are in their natural state (Craft and Richardson, 1998; Moorhead and Brinson, 1995). The altered drainage patterns, however, appear to be limiting their vertical accretion—and saltwater intrusion could cause subsidence and conversion to open water. Rather than helping the ecosystem respond to rising sea level, human activities appear to be disabling the processes that could otherwise allow these wetlands to stay ahead of the rising sea.

This section examines the types of wetlands in this area and the landscapes where they are found, followed by shoreline erosion and some of the rates at which it has been measured in different settings. We then discuss how wetlands affect the position of the shoreline and ways wetlands can respond to sea-level rise. Some wetlands, particularly marshes and swamps, can migrate landward as sea level rises, particularly if the slope of the land is gradual. Finally, we discuss some of the environmental effects of wetlands loss.

G.3.1 Distribution of Wetland Types

The Albemarle-Pamlico Sound system includes most of the major estuaries in North Carolina. The Albemarle Sound receives drainage from the Chowan and Roanoke Rivers (as well as Currituck Sound and Back Bay in Virginia Beach) and the Pamlico Sound receives drainage from the Tar and Neuse Rivers. All of these rivers deliver substantial quantities of sediments that are either deposited on adjacent floodplains or are carried into the Albemarle Sound and the Pamlico River and Neuse estuaries. Deposition rates of these sediments in the estuaries approximate the rate of rising sea level (2-3 mm/yr) (Benninger and Wells, 1993). These sediments generally do not reach coastal marshes, in part because they are deposited in subtidal areas and in part because there is little or no astronomic tide to carry them to wetland surfaces. Storms that generate high water levels, especially ‘northeasters’ that raise water levels in the southern portions of Pamlico Sound, deposit sediments on storm levees adjacent to marsh shorelines. Most tributaries that drain the coastal plain are a minor supply of suspended sediment to the estuaries (Riggs, 1996).

While many wetlands in coastal North Carolina formed in similar geologic settings, different types of wetlands emerged. Poorly drained flat plains between streams (known as inter-stream divides) typify the Albemarle-Pamlico Peninsula. Portions of these areas are locally known as "pocosins," which refers to a plant community of evergreen shrubs and wetland tree species occupying peat deposits[181]. Rising sea level has now reached some peatlands, particularly those at lower elevations, *e.g.*, in Dare County, on the extreme eastern end of the Albemarle-Pamlico peninsula. As a result, scarped peat shorelines (*i.e.*, peat shorelines with steep vertical drop-offs created by waves) are extensive (Riggs and Ames, 2003).

Other types of wetlands, including large areas of marshes and forested wetlands, are also influenced by sea level. Many are classified as fringe wetlands because they occur along the periphery of estuaries that flood them irregularly. Salinity is the major control that determines the dominant vegetation type. In the fresh to slightly brackish (oligohaline) Albemarle Sound region, forested shrub-scrub wetlands dominate. Forested wetlands also occur on floodplains of the major rivers (Chowan, Roanoke, Tar, and Neuse), as well as tributaries draining pocosins and other areas of the coastal plain. As the shoreline erodes in areas with forested wetlands, bald cypress trees become stranded in the permanently flooded zone. They eventually die and fall down, which creates a zone in shallow water with a complex habitat structure, including fallen trees and relic "knees" cypress trees once sprouted for support. Landward, one finds a "storm levee" (coarse sand deposited during storms) bordering the swamp forest in areas exposed to waves. These forests are described as "tidal cypress-gum swamp." (Shafale and Weakley, 1990) They can range from gum-maple swamps on mineral soils to evergreen shrub bogs (pocosins) growing on peaty deposits.

Salinity is an important factor that affects the types of vegetation found in a given area. Trees are killed by extended exposure to salinity above 10 ppt (approximately 1/4 -1/3 the salinity of sea water), and the growth of most trees and shrubs is restricted at much lower salinities (Conner *et al.*, 1997; Poulter *et al.*, 2008). In brackish water areas, marshes consisting of plants that are saltwater-tolerant replace forested wetlands. Along the Pamlico Sound, a large area consists of brackish marshes. Marshes are largely absent from the shore of Albemarle Sound and mouths of the Tar and Neuse Rivers, where salinities are too low to affect vegetation. It is only the lower reaches of the Chowan, Roanoke, Tar, and Neuse rivers that are affected by rising sea level. Along small tributaries of the Neuse and Pamlico River estuaries, there are brackish marshes at estuary mouths and forested wetlands in regions further upstream, where the salinity is low (Brinson *et al.*, 1985).

Sea level influences the location of the boundaries between wetlands and uplands, in part because estuarine water levels can drive poor drainage of coastal wetlands. These boundaries are commonly found where brackish water from storm surges has created a transition between salt-tolerant marshes and upland forest. Sea level also may influence the zones different plant communities occupy. For example, where waves have raised the elevation of wetlands by depositing sediment on "storm levees" on the shore of marshes, the elevation tends to be higher than in adjacent areas, and therefore different types of plants tend to be found there.

G.3.2 Estuarine Shoreline Erosion

Rising sea level is not the primary cause of shoreline retreat along estuarine shores in North Carolina. Storm waves cause shorelines to recede whether or not the sea is rising. Nevertheless, rising sea level can indirectly increase the erosive power of storm waves, and decrease the ability of shores to advance between storms. (See Chapter 2). A study of 21 sites estimated that shoreline retreat — caused by "the intimately coupled processes of wave action and rising sea level" — is already eliminating wetlands at a rate of about 3.2 square kilometers (800 acres) per year, mostly in zones of brackish marsh habitat, such as on the Albemarle-Pamlico Peninsula (Riggs and Ames, 2003).

Riggs and Ames (2003) compiled data collected across North Carolina shorelines, both those that are adjacent to wetlands and those that are not. These data show that the vast majority of estuarine shores in the region are eroding, except for the sound sides of barrier islands (which one might expect to advance toward the mainland). Shores have retreated almost 2 m per year, over periods as long as 30 years. Annual averages for most shoreline types are less than 1 m per year, (Table G.2) but annual maxima exceed the average many-fold and can reach 8 m per year where the shoreline is characterized by sediment bluffs or high banks. One or a few individual storm events contribute disproportionately to average annual shoreline recession rates (Riggs and Ames, 2003). Variables that affect erosion rates include number and pattern of seasonal storms, fetch (the distance waves travel over open water), shoreline type, composition of soil, presence and type of vegetation, and depth of water near the shore.

Table G.2 Estuarine shoreline erosion rates by shoreline type and the percent of total shoreline for each type. From Riggs and Ames (2003), Table 9-1-5, at 145.

Shoreline type	Percent of shoreline	Maximum rate per year (m)	Average rate per year (m)
Sediment Bank			
Sediment low bank	30	2.7	1.0
Sediment bluff/high bank	8	8.0	0.8
Back-barrier strandplain	?	0.6	-0.2*
Organic Shoreline			
Mainland marsh	55	5.6	0.9
Back-barrier marsh	?	5.8	0.4
Swamp forest	7	1.8	0.7
Total			2.7

G.3.3 Will Wetlands Keep Pace With Rising Sea Level?

Although wetlands are retreating at their seaward boundaries, away from the shore, most marshes and swamps in North Carolina appear to be keeping pace with rising sea level. As we look into the future, three scenarios seem possible:

Continuation of current trends. If sea level continues to rise approximately 3 mm/year, most wetlands are unlikely to drown, although some wetland will be lost as shores retreat.

Wetland drowning, however, may result if rates of sea-level rise increase by 2 mm/yr, and is likely if rates increase by 7 mm/yr[182]. Under the drowning scenario, the low-lying wetlands of the lower coastal plain would convert to aquatic ecosystems, and the large, low, and flat pocosin would transform from forest to aquatic habitat (Poulter, 2005). In areas of pocosin peatland, shrub and forest vegetation first would be killed by brackish water. In contrast to fringe wetlands, swamp forest wetlands along the piedmont-draining rivers are likely to sustain themselves under the drowning scenario. This is due to the general abundance of mineral sediments when rivers overflow their banks. This applies to regions within the floodplain, but not at river mouths. Also, pocosin swamp forest peatlands at higher elevations in the coastal plain will continue to grow vertically, independently of sea-level rise and of mineral sediment supplies since they are disconnected from the riverine and estuarine systems.

Barrier islands are breached. Chapter 6 suggests that more inlets are likely, and that disintegration of some of the barrier islands is possible if sea-level rise accelerates. This would cause a state change from a non-tidal to tidal regime as additional inlets open, causing the Albemarle and Pamlico Sounds to have a significant tide range and increased salinity. Poulter (2005) estimated that conversion from a non-tidal to tidal estuary might expose hundreds of square kilometers of nontidal wetlands to tidal flooding. In theory, it is possible that this transformation might increase the ability of wetland to keep pace with rising sea level by increasing the supply of sediment. The conversion of Pamlico Sound to a tidal system would likely re-establish tidal channels where ancestral streams were located. The remobilization of sediments could then supply existing marshes with inorganic sediments. It is more likely, however, that marshes would become established landward on newly inundated mineral soils of former uplands.

As sea level rises further and waters with higher salt content reach the peninsula, the ability of peat-based wetlands to keep up is doubtful (Riggs, 2006). In peatlands, shrub and forest vegetation first would be killed by brackish water. It is unlikely that pocosin and swamp forest areas would convert to tidal wetlands, for two reasons. First, the root mat within them would collapse due to plant mortality and decomposition, causing a rapid subsidence of several centimeters[183]. Second, brackish water may accelerate decomposition of peat. When seawater reaches peat soils, a group of sulfate-metabolizing bacteria begin to digest the soil at a much faster rate than the normal methane-producing bacteria that inhabit freshwater peat soils (Portnoy and Giblin, 1997). Further, the death of woody vegetation and fact that wetland plants can no longer become established results in the exposure of organic-rich soils directly to decomposition, erosion, suspension, and transport, without the stabilizing properties of vegetation (Henman and Poulter, 2008; IPCC, 2007).

G.3.4 Environmental Implications of Habitat Loss and Shore Protection

North Carolina's coastal wetlands provide important habitat for many species. Human activities to control shoreline erosion and flooding, however, are already harming wetlands. Nontidal wetlands account for more than 69 percent of the land within one meter above spring high water.

Ecological/habitat processes and patterns. Some wetland functions are proportional to size. Other functions depend on the wetland's edges, that is, the borders between open water and wetland. Because of the large size of many irregularly flooded marshes in the region, their interior portions are effectively isolated from the aquatic portions of the estuary.

In the absence of tidal creeks and astronomic tidal currents, pathways for fish and invertebrate movement are severely restricted. In contrast, the twice-daily inundation of tidal marshes increases connections across the aquatic-wetland edge, as does the presence of tidal creeks, which allow fish and aquatic invertebrates to exploit intertidal areas (Kneib and Wagner, 1994). Mobility across ecosystem boundaries is less prevalent in irregularly flooded marshes, where some fish species become marsh "residents" because of the long distances required to navigate from marshes to subtidal habitats (Marraro *et al.*, 1991). Where irregularly-flooded marshes are inundated for weeks at a time, little is known about how resident species adapt. These include, among other species, several types of fish (*e.g.*, killifish and mummichogs), brown water snakes, crustaceans (various species of crabs), birds (yellowthroat, marsh wren, harrier, swamp sparrow, and five species of rails), and several species of mammals (nutria, cotton rat, and raccoon). North Carolina's coastal marshes are also home to a reintroduced population of red wolves (see Box G.1).

BOX G.1: Reintroduced population of red wolves in North Carolina

***Red Wolf** (Canus rufus)*

Photograph credit: U.S. Fish and Wildlife Service. Red Wolf Recovery Project. Photos. Accessed at: http://www.fws.gov/alligatorriver/red wolf/rwpics.html on March 12, 2007. Photo: Greg Koch

Habitat: The red wolf (*Canus rufus*) is federally listed as endangered and was formerly extinct in the wild. Red wolves were hunted and trapped aggressively in the early 1900s as the southeast became increasingly developed, and the remaining wolves then suffered further declines with the extensive clearing of forest and hardwood river bottoms that formed much of the prime red wolf habitat (USFWS, 1993; USFWS, 2004). The last wild red wolves were found in coastal prairie and marsh habitat, having been pushed to the edges of their range in Louisiana and Texas. The red wolf is elusive, and most active at dawn and dusk. It lives in packs of five to eight animals, and feeds on white-tailed deer, raccoon, rabbit, nutria, and other rodents. In addition to food and water in a large home range area (25 to 50 square miles), red wolves require heavy vegetation cover (USFWS, 1993).

Locations: Through a captive breeding program and reintroduction of the species, there are now an estimated total of 100 red wolves living in the wild in coastal areas of North Carolina. In the wild, the red wolf currently occupies approximately 1.7 million acres on three national wildlife refuges and other public and private lands in eastern North Carolina. Principal among these areas is the Alligator River National Wildlife Refuge (NWR), the site of the red wolf's reintroduction to the wild in 1987 (USFWS, 2006). The refuge is surrounded on three sides by coastal waters and connected to the mainland by a largely developed area. Red wolves have also been reintroduced to the Pocosin Lakes NWR, slightly inland from Alligator River NWR, and are occasionally sighted on the Mattamuskeet NWR. The last wild red wolves were found in Louisiana and Texas coastal marsh areas, but their historic range extended from southern Pennsylvania throughout the southeast and west as far as central Texas (USFWS, 2004). Despite their potential for survival in numerous habitat types throughout the southeastern United States, the small current population faces serious threats from sea level rise.

Impact of Sea Level Rise: Alligator River National Wildlife Refuge (NWR), the red wolf's primary population center is at risk due to sea level rise. Developed areas inland of the peninsular refuge limit habitat migration potential. In a 2006 report, the Defenders of Wildlife (an environmental advocacy organization) characterized Alligator River NWR as one of the ten NWRs most gravely at risk due to sea level rise. The effects of sea level rise can already be seen on the habitat in Alligator NWR, where pond pine forest has transitioned into a sawgrass marsh in one area, and the peat soils of canal banks are eroding near the sounds (Stewart, 2006). Areas of hardwood forest and pocosin will be replaced by expanding grass-dominated freshwater marshes currently occupying the edges of the sounds. Bald cypress and swamp tupelo forests will also replace the hardwood areas (USFWS, 2006). The red wolf is not likely to adapt to the marsh habitat in the short amount of time that these processes are already taking place (Stewart, 2006).

Effects of human activities. Human alterations, including bulkheads and other shore protection structures, have served mostly to stabilize the position of coastal wetlands and thus resist effects of both rising sea level and erosion.

Levees associated with waterfowl impoundments have isolated large marsh areas in southern Pamlico Sound from any connection with estuarine waters. Impoundments were built to create a freshwater environment conducive to migratory duck populations and thus eliminate most other habitat functions mentioned above for brackish marshes. Further, isolation from sea level influences has likely disconnected the impoundment from pre-existing hydrologic gradients that would promote vertical accretion of marsh soil. If the impoundments were opened to an estuarine connection after decades of isolation, they would likely become shallow, open-water areas incapable of reverting to wetlands (Day *et al.*, 1990).

Drainage ditches, installed to drain land so that it would be suitable for agriculture, are prevalent in North Carolina. By the 1970s, on the Albemarle-Pamlico Peninsula, there were an estimated 20 miles of streams and artificial drainage channels per square mile of land, while the ratio in other parts of North Carolina ranged from 1.4–2.8 to 1 (Heath, 1975). In many cases, ditches, some of which were dug more than a century ago to drain farmland (Lilly, 1981) now serve to transport brackish water landward, a problem that could become increasingly prevalent as sea level rises. Saltwater intrusion to agricultural soils is a major consequence of this process. A number of tide gates have been installed on the Albemarle-Pamlico Peninsula to reduce brackish water intrusion. Numerous canals and ditches in the Alligator River and Pocosin Lakes National Wildlife Refuges likewise carry brackish water inland, reversing intended flow directions. Brackish water may not only alter vegetation type in an area, but peat can collapse from the intrusion of sulfate-rich, brackish water. Studies are ongoing to understand the current and future effects of drainage networks (Poulter , Goodall and Halpin, in review).

Potential effects of human activities at the marsh-forest boundary on overland migration of wetlands are more subtle. The conversion of marsh into forest is an ongoing process that can expand or maintain marsh surface area that would otherwise be diminished by shoreline retreat. Existing structures can interfere with these processes, and new ones are being constructed in association with increasing shoreline and shore zone development. Highway and railroad beds directly impede wetland migration. Even those with culverts would hinder overland flow of water and slow wetland migration. Levees constructed to protect property from storm surges, dense housing developments with extensive bulkheads, and new highways and streets have similar effects.

G.4 DEVELOPMENT AND SHORE PROTECTION

G.4.1 Statewide Policy Context

Several North Carolina laws and regulations have an impact on response to sea-level rise within the state. First, setback rules encourage retreat by requiring buildings being constructed or reconstructed to be set back a certain distance from where the shoreline is located when construction permits are issued. Second, North Carolina does not allow shore protection structures such as seawalls and revetments on oceanfront shorelines,[184] preventing property owners from employing one possible method of holding back the sea to protect their property.[185]. Adding sand to beaches (*i.e.*, beach nourishment) is the preferred method in North Carolina to protect buildings near the ocean coastline. In addition, the State requires coastal counties to adopt land use plans to guide future development, and these plans are supposed to take into account sea-level rise[186]. In most county land use plans, this component does not explicitly address how the county will address sea-level rise, but land use plans are updated regularly (Feldman, 2007, pp. 64-65; Feldman, 2008, p. 5). The requirement could encourage counties to give more thought to how the areas most likely to be impacted by sea-level rise should respond in the future. Finally, the North Carolina Division of Coastal Management analyzes information and educates the public about shoreline change and coastal hazards in the state, and its efforts could heighten public awareness about sea-level rise vulnerability in North Carolina's coastal counties (Feldman, 2008).

North Carolina's Coastal Area Management Act and Dredge and Fill Law authorizes the Coastal Resources Commission (CRC) to regulate certain aspects of development within North Carolina's 20 coastal counties[187]. For example, the CRC issues permits for development and classifies certain regions as Areas of Environmental Concern (*e.g.*, ocean hazard zones and coastal wetlands) where special rules governing development apply. In response to the threat of damage to coastal structures from the waves, North Carolina has required since 1980 new development to be set back from the oceanfront. The setbacks are measured from the first line of stable natural vegetation[188]. Single-family homes of any size—as well as multi-family homes and non-residential structures with less than 5,000 square feet of floor area--must be set back by 60 feet or 30 times the long-term rate of erosion as calculated by the state, whichever is greater. Larger multi-family homes and non-residential structures must be set back by 120 feet or the erosion-based setback distance, whichever is greater. The setback distance for these larger structures is calculated as either 60 times the annual erosion rate or 105 feet plus 30 times the erosion rate, whichever is less[189]. North Carolina is considering changes to its oceanfront setback rules, including progressively larger setback factors for buildings with 10,000 square feet of floor area or more (NC CRC, 2007, p.1). Along estuarine shorelines, North Carolina has a 30-foot setback[190] and restricts development between 30 and 75 feet from the shore[191]. As the shore moves inland, these setback lines move inland as well.

As of 2000, the U.S. Army Corps of Engineers participated in beach nourishment projects along more than 32 miles of North Carolina's shoreline (including some nourishment projects that occurred as a result of nearby dredging projects), and nourishment along an additional 85 miles of coastline had been proposed (USACOE, 2000)[192]. If necessary, property owners can place large (geotextile) sandbags in front of buildings to attempt to protect them from the waves. Standards apply to the placement of sandbags, which is supposed to be temporary (to protect structures during and after a major storm or other short-term event that causes erosion, or to allow time for relocation)[193]. Buildings are supposed to be moved or removed within two years of becoming "imminently threatened" by shoreline changes[194]. Furthermore, there is no ban on hardened structures along estuarine shorelines, as long as they are built landward of wetlands[195]. State guidelines for siting and constructing estuarine hardened structures are under review by the Coastal Resources Commission (see, *e.g.*, Feldman, 2008, p. 5).

The Coastal Area Management Act also requires that coastal counties develop and periodically update land use plans, which are binding in Areas of Environmental Concern. One of the hazards that these land use plans are supposed to take into account is sea-level rise, but most plans either do not include policies tailored to areas threatened by sea-level rise, address it only in passing, or defer to the state to take action.

North Carolina officials are in the process of reassessing certain state policies in light of the forces of shoreline change and climate change. Policy considerations have been affected by numerous studies that researchers have published on the potential effects of sea-level rise on North Carolina (Poulter *et al.*, in review). The state legislature appointed a Legislative Commission on Global Climate Change to study and report on potential climate change effects and potential mitigation strategies, including by providing recommendations that address impacts on the coastal zone (see the "North Carolina Global Warming Act," Session Law 2005-442. The Commission's recommendations have not yet been finalized, but a draft version offered such suggestions as creating a mechanism to purchase land or conservation easements in low-lying areas at great risk from sea-level rise; providing incentives for controlling erosion along estuarine shorelines using ecologically beneficial methods; creating a commission to study adaptation to climate change and make recommendations about controversial issues; and inventorying, mapping, and monitoring the physical and biological characteristics of the entire shoreline (Feldman, 2007, pp. 42-42; Feldman, 2008, p. 8; Riggs, Stephenson, and Clark 2007). The Coastal Resources Commission is also considering the potential effects of sea-level rise and whether to recommend any changes to its rules affecting development in coastal areas (Feldman, 2008, p.6). In addition, NCDCM is developing a Beach and Inlet Management Plan to define beach and inlet management zones and propose preliminary management strategies given natural forces, economic factors, limitations to the supply of beach-quality sand, and other constraints (Moffatt and Nichol, 2007).

G.4.2 Current Land Use

As discussed in Chapter 5, ongoing studies have combined land use data, regulations, and planner expectations for future development to create alternative scenarios of shore-protection and wetland migration. Because those studies have not yet been published in peer review journal articles, we describe some of the aspects of land use that would influence whether people hold back the sea or allow wetlands and beaches to migrate inland.

Ocean Coast. North Carolina's ocean coast, like the coasts of most states, includes moderate and densely developed communities, as well as undeveloped roadless barrier islands. Unlike other mid-Atlantic states, North Carolina's coast also includes a roadless coastal barrier that is nevertheless being developed, densely populated areas that nevertheless have been yielding homes to the sea, and a major lighthouse that has been relocated landward.

The northern 23 kilometers of the state's coastline is a designated undeveloped coastal barrier and hence ineligible for most federal programs (USFWS, not dated). This stretch of barrier island includes two sections of Currituck National Wildlife Refuge, each about 2 kilometers long, which are both off-limits to development and make it infeasible for the County to even consider a road along the barrier island (NC DOT, not dated). Nevertheless, the privately owned areas are gradually being developed, even though they are accessible only by boat or four-wheel drive vehicles traveling along the beach. The roadless areas are ineligible for federal beach nourishment and flood insurance.

Along the Dare County coast from Kitty Hawk to Nags Head, federal legislation has authorized shore protection, provided that it is cost-effective. Homes have been falling into the water as shores erode; but now that the through streets parallel to the shore are at risk, small sand replenishment projects have been undertaken to protect these roads. The beaches in some of the communities north of Kitty Hawk are not yet open to the public, and hence they are currently ineligible for beach nourishment.

From Nags Head to Hatteras Island, most of the coast is part of Cape Hatteras National Seashore, with a coastal highway running the entire length, from which one can catch a ferry to Ocracoke Island. Congress appropriated $9.8 million to move the Cape Hatteras Lighthouse 1,600 feet inland (NPS, 2000). The National Park Service generally allows shores to retreat, and the road has been relocated inland in places. Nevertheless, the coastal coastal highway is essential infrastructure, the protection of which would require maintaining the barrier island. A possible exception is that part of Hatteras Island between Rodanthe and Oregon Inlet. The federal and state governments are considering the possibility that when a new bridge is built over Oregon Inlet, that it would run over Pamlico sound just west of Hatteras Island, as far as Rodanthe.

Southwest of Cape Lookout, the coast consists mostly of developed barrier islands, , conservation lands that will not be protected, and designated “undeveloped coastal barriers” that are nevertheless being developed. The undeveloped Portsmouth Island and Core Banks constitute Cape Lookout National Seashore., and lack road access. Cape Lookout is located on Core Banks. Shackleford Banks, immediately adjacent to the southwest, is roadless and uninhabited. To its west, Bogue Banks includes five large communities with high dunes and dense forests (Pilkey *et al.*, 1998). The island also receives fill to widen its beaches regularly.

To the west of Bogue Banks are the barrier islands of Onslow County and then Pender County. Some islands are only accessible by boat, and most of these are undeveloped. North Topsail Beach, on Topsail Island, has been devastated by multiple hurricanes, in part due to its low elevation and the narrow width of Topsail Island. Erosion has forced multiple roads on the island to be moved. While some parts of North Topsail Beach are part of a unit under the Coastal Barrier Resources Act (CBRA) system, making them ineligible for federal subsidies, development has occurred within them nonetheless (Pilkey *et al.*, 1998).

Further to the west are the barrier islands of New Hanover County. An exclusive residential neighborhood is located on Figure Eight Island. Wrightsville Beach, like many other communities southwest of Cape Lookout, has an inlet on each side. It is the site of a well-known battle to protect a hotel from being washed away due to inlet migration. The U.S. Army Corps of Engineers has committed, over the long term, to regular beach renourishment to maintain the place of the shoreline in Wrightsville Beach and Carolina Beach (USACOE, 2006 p.38). An exception to North Carolina's rules forbidding hardened structures has been granted in Kure Beach, west of Carolina Beach, where rock rip-rap has been placed on the oceanfront to protect Fort Fisher (which dates back to the Civil War) (Pilkey *et al.*, 1998). The rip-rap also protects a highway that provides access to the area. Most of the beach communities in New Hanover County are extensively developed.

Some of the barrier islands in Brunswick County are heavily forested with high elevations, making them more resilient to coastal hazards (Pilkey *et al.*, 1998). Holden Beach and Ocean Isle Beach, however, contain many dredge-and-fill finger canals. Historically, at least two inlets cut through Holden Beach; and storms could create new inlets where there are currently canals (Pilkey *et al.*, 1998).

Estuarine Shores. Significant urbanization was slow to come to this region for many reasons. Most of the area is farther from population centers than the Delaware and Chesapeake estuaries. The Outer Banks were developed more slowly than the barrier islands of New Jersey, Delaware, and Maryland. And most importantly, the land is mostly low and wet. With more than 60 percent of the land within the Mid-Atlantic that might realistically be allowed to become submerged as sea level rises, this area represents an environmental planning opportunity that is of national importance.

The lands along the Albemarle and Pamlico sounds account for 70 percent of the nontidal wetlands, 40 percent of the dry land, and 55 percent of all the land in the Mid-Atlantic within 1 meter above spring high water.(Titus and Wang, 2008) They include about 50 percent of the dry land where protection is precluded or unlikely, and 63 percent of all land within the Mid-Atlantic that is likely to be submerged, assuming that nontidal wetlands are also allowed to flood (See Chapter 1).

Unlike the Delaware Estuary, communities in North Carolina do not have a long history of diking tidal wetlands to reclaim land from the sea for agricultural purposes[196]. But they are starting to gain experience with dikes to protect agricultural lands from flooding. In Tyrrell County, the Gum Neck has been protected with a dike for four decades. A dike is now planned for the town and farms around Swan Quarter, the county seat of Hyde County (which includes Ocracoke Island). Especially in Tyrell County, shore protection is a matter of self-preservation to this county. Hurricane Floyd led Pamlico County to encourage people to gradually abandon the eastern portion of the county, by working with FEMA to relocate people rather than rebuild damaged homes (Barnes, 2001). In parts of Carteret County, by contrast, people learned the opposite lesson and elevated homes. Hyde County is building a dike around its county seat and many farms nearby.

G.5 POPULATION OF LANDS CLOSE TO SEA LEVEL

Approximately 900,000 people live in the 20 coastal counties in North Carolina. The economies of these counties are dependent on agriculture, forestry, and tourism. Tourism is associated with coastal development and beach visits, as well as recreational sports and fishing. Bin *et al.*, (2007) estimated the economic costs of climate change in coastal North Carolina by evaluating impacts on tourism (beach visits and fishing), private property, and the business sector. They considered losses of beach width and fishing locations due to increased shoreline erosion from sea-level rise, loss of property value from direct inundation, and business interruptions from increased frequency of hurricanes associated with increasing sea surface temperatures.

In just four coastal counties (representing a cross-section of economic characteristics and vulnerability to sea-level rise), between 2 and 12% of properties were at risk from an 81 cm rise in sea level by the year 2080. The value of lost residential and nonresidential property in these four counties was estimated at $6.9 billion in 2080 (adjusted for a 2% discount rate) (Bin *et al.*, 2007). Impacts of sea-level rise on tourism, including recreational fishing, were based on the assumption that wider beaches are more frequently visited than narrower beaches. The study estimated that the lost recreational value ranged up to $3.5 billion for the southern North Carolina beaches, while lost fishing opportunities ranged up to $430 million (both estimates assumed a 2% discount rate) (Bin *et al.*, 2007).Lastly, business interruptions from changes in hurricane frequency and intensity were estimated, however the uncertainty regarding the relationship between climate change and hurricane characteristics is highly uncertain. The authors estimated that business impacts could increase 150% if hurricane intensity increases from Category 2 to 3 (Bin *et al.*, 2007).

BOX G.2: Vulnerability of the Albemarle-Pamlico Peninsula and Emerging Stakeholder Response

Vulnerability to sea level rise on the diverse Albemarle-Pamlico Peninsula is very high: about two-thirds of the peninsula is less than 5 feet above sea level (Heath, 1975), and approximately 30 percent is less than 3 feet above sea level (Poulter, 2005). Erosion rates in parts of the peninsula are already high. For example, along bluffs, erosion rates up to 25 feet per year have been measured (Riggs and Ames, 2003). The ecosystems of the Albemarle-Pamlico Peninsula have long been recognized for their biological and ecological value. The peninsula is home to four national wildlife refuges, the first of which was established in 1932. In all, about a fourth of the peninsula has been set aside for conservation purposes.

The Albemarle-Pamlico Peninsula is among North Carolina's poorest areas. Four of its five counties are classified as economically distressed by the state, with high poverty and unemployment rates, along with low wages. However, now that undeveloped waterfront property on the Outer Banks is very expensive and very scarce, developers have discovered the small fishing villages on the peninsula and begun acquiring property in several areas—including Columbia (Tyrell County), Engelhard (Hyde County) and Bath (Beaufort County). The peninsula is being marketed as the "Inner Banks." Communities across the peninsula are planning infrastructure, including wastewater treatment facilities and desalination plants for drinking water, to enable new development. Columbia and Plymouth (Washington County) have become demonstration sites in the North Carolina Rural Economic Development Center's STEP (Small Towns Economic Prosperity) Program, which is designed to support revitalization and provide information vital to developing public policies that support long-term investment in small towns (NC REDC, 2006).

There are already signs that sea level rise is causing ecosystems on the Albemarle-Pamlico Peninsula to change. For example, at the Buckridge Coastal Reserve, an 18,650-acre area owned by DCM, dieback is occurring in several areas of Atlantic white cedar. Other parts of the cedar community are beginning to show signs of stress. Initial investigations suggest the dieback is associated with altered hydrologic conditions, due to canals and ditches serving as conduits that bring salt and brackish water into the peat soils where cedar usually grows. Storm or wind events have pushed estuarine water into areas that are naturally fresh, affecting water chemistry, peatland soils, and vegetation intolerant of saline conditions (Poulter and Pederson, 2006).

There is growing awareness on the part of residents of the Albemarle-Pamlico Peninsula and local officials about potential vulnerabilities across the landscape. Many farmers acknowledge that salt intrusion and sea level rise are affecting their fields. Researchers at North Carolina State University are using Hyde County farms to experiment with the development of new varieties of salt-tolerant soybeans (NC SGA, 2002). Hyde County is building a dike around Swan Quarter, the county seat.

A variety of evidence has suggested to some stakeholders that the risks to the Albemarle-Pamlico Peninsula merit special management responses. In fact, because so much of the landscape across the peninsula has been transformed by humans, some have expressed concern that the ecosystem may be less resilient and less likely to be able to adapt when exposed to mounting stresses (Pearsall et al. 2005). Thus far, no comprehensive long-term response to the effects of sea level rise on the peninsula has been proposed. In 2007, The Nature Conservancy, Environmental Defense, Ducks Unlimited, the North Carolina Coastal Federation and others began working to build an Albemarle Conservation Partnership to develop a long-term strategic vision for the peninsula. Although this initiative is only in its infancy, sea level rise will be one of the first and most important issues the partnership will address.

The Nature Conservancy and others have already identified several potential responses to sea level rise on the Albemarle-Pamlico Peninsula. These approaches require community participation in conservation efforts, land protection, and adaptive management (Heath, 1975). Specific management strategies that the Nature Conservancy and others have recommended include: plugging drainage ditches and installing tide gates in agricultural fields so that sea water does not flow inland through them, establishing cypress trees where land has been cleared in areas that are expected to become wetlands in the future, reestablishing brackish marshes in hospitable areas where it is absent and areas that are likely to become wetlands in the future, creating corridors that run from the shoreline inland (which could facilitate habitat migration), reducing habitat fragmentation, banning or restricting hardened structures along the estuarine shoreline, and establishing submerged aquatic vegetation beds offshore (Pearsall and DeBlieu, 2005).

Table G.3 estimates the population of lands close to sea level in North Carolina. Because Census data for population is based on year-round residents, the estimates for many of the ocean coastal counties--especially Dare--would be greater if summer residents were included. The calculations assume that population is proportionately allocated in census blocks with high densities that are not along the open water. Therefore, the estimates for New Hanover County include residents of multifamily units on a census block that might have some low land along a historic or ancient creek. (See Chapter 6.)

Table G.3 Population of lands close to sea level: North Carolina.

County	Low and high estimates of population below a given elevation (thousands)					
	50cm		1m		2m	
	Low	High	Low	High	Low	High
North Carolina						
Beaufort	0.1	1.5	0.6	3.8	4.9	9.2
Brunswick	0.1	0.3	0.2	0.8	1.2	1.8
Camden	0.0	0.1	0.0	0.2	0.5	2.5
Carteret	0.4	2.1	1.2	5.3	8.4	14.6
Chowan	0.0	0.2	0.1	0.2	0.3	0.4
Craven	0.3	0.7	0.4	2.7	4.1	8.3
Currituck	0.0	0.2	0.1	0.7	1.2	3.2
Dare	0.0	1.9	1.1	5.1	7.3	11.9
Hyde	0.0	1.5	1.0	3.0	3.3	4.8
New Hanover	0.1	4.5	3.8	7.4	8.3	11.2
Onslow	0.3	0.8	0.7	1.1	1.3	2.8
Pamlico	0.0	0.3	0.3	0.7	1.3	2.7
Pasquotank	0.2	2.8	2.3	5.7	9.7	17.1
Pender	0.0	0.1	0.1	0.3	0.6	1.0
Perquimans	0.2	0.2	0.2	0.2	0.4	1.1
Tyrrell	0.0	1.4	0.9	2.3	3.1	3.6
Washington	0.0	0.1	0.1	0.2	0.3	1.2
Total	**1.6**	**18.6**	**12.9**	**39.7**	**56.2**	**97.5**

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