

Protecting beaches and sea turtles:
An analysis of beach nourishment in North Carolina, the impacts on nesting
loggerhead sea turtles, and how sea level rise will transform the status quo.

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Abstract

Federally protected loggerhead sea turtles rely on wide sandy beaches for their terrestrial reproductive phase. Accustomed to hurricanes and erosion, North Carolina has taken to extensive beach nourishment efforts for shoreline protection. The majority of these efforts have been to benefit interests other than sea turtles, but given the recent critical habitat proposals for the Northwest Atlantic Ocean Distinct Population Segment of the Loggerhead Sea Turtle (*Caretta caretta*), submitted by the US Fish and Wildlife Service and the National Marine Fisheries Service in 2013, their consideration warrants further attention.

Each beach selected for my study: 1) is a known loggerhead sea turtle nesting beach; 2) is within the proposed terrestrial critical habitat; 3) has a “High” to “Extremely High” vulnerability to sea level rise based on the US Geological Survey Coastal Vulnerability Index; and 4) is a developed barrier island. The final economic analysis was on Bogue Banks (Carteret County), Pleasure Island (New Hanover County), and Bald Head Island, Oak Island, and Holden Beach (Brunswick County). In this project, I explored historic nourishment data to understand the full costs of beach protection, hypothesizing that sea level rise will exacerbate that cost in the future.

Through my research, I unveiled how nourishment efforts potentially both help and hinder the state and sea turtles. My analysis uncovered ways North Carolina can responsibly move forward with beach protection while taking both sea turtles and sea level rise into account. First, there must be state-level support for sea level rise planning – the Coastal Resources Commission should move forward with sea level rise discussions and define a rate of sea level change for planning purposes. This rate, and associated increased need for sand, should be incorporated into future nourishment projects so the US Army Corps of Engineers and the North Carolina Division of Coastal Management do not underestimate costs and how much sand will be needed over the lifetime of each project. County and municipal governments should also devise local tax plans to finance future nourishment projects. Finally, the US Army Corps of Engineers, the state Wildlife Resource Commission, and local sea turtle volunteer groups should continue monitoring nesting beaches for any changes post-nourishment to further understand how modified beaches impact loggerhead sea turtles.

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“When we try to pick out anything by itself,
we find it hitched to everything else in the Universe.”

- John Muir, *My First Summer in the Sierra* (1911)

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Introduction

Climate change and sea level rise occur globally, but efforts to deter the rising seas will first occur at the state and local level (Karetinkov et al. 2008). North Carolina's iconic sandy beaches draw thousands of tourists annually, generating millions in economic revenue (Department of Commerce 2013), but are threatened by future sea level change. Wide, stable beaches provide protective benefits to coastal property owners, renters, and businesses, as well as to developers interested in capitalizing on the picturesque coastline. Given that beaches are dynamic and naturally erode and accrete over time, a challenge for coastal managers is how to protect investments while maintaining the ecological integrity of the system. One key component of this system often overlooked is the federally threatened loggerhead sea turtle (*Caretta caretta*). This paper explores how beach preservation and sea level rise adaptation efforts in North Carolina may come into repeated conflict with loggerhead nesting as the climate changes and sea levels rise.

Sea turtles spend most of their life at sea, but the critical female reproductive stage takes place on sandy beaches worldwide (Dodd 1988). About 330 miles of the North Carolina coastline is suitable nesting habitat for sea turtles (WRC 2013), but much of this coast is developed. The demand for limited beach space will only continue as sea levels rise and beaches are wedged between the rising oceans and coastal development (Fish et al. 2005; Mazaris et al. 2009). Accelerated rates of erosion due to sea level rise will both exacerbate the need to actively protect the shoreline, and at the same time limit the availability of suitable nesting sites for female sea turtles (Fish et al. 2005; Mazaris et al. 2009).

In September 2011, under the Endangered Species Act (ESA), the National Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (FWS) jointly issued a rule listing nine Distinct Population Segments (DPS) of loggerhead sea turtles (76 FR 58868). This action labeled each DPS as either threatened or endangered and allowed for more focused critical habitat designations and conservation efforts (NOAA 2011). Loggerhead sea turtles in North Carolina were determined to be part of the Northwest Atlantic DPS and designated as threatened (76 FR 58868). In March 2013, the FWS submitted for public comment the "Proposed Designation of Terrestrial Critical Habitat for the Northwest Atlantic Ocean Distinct Population Segment of the Loggerhead Sea Turtle." Included in this critical habitat proposal are 96.1 miles of North Carolina ocean-side beaches, including Bogue Banks, Bear Island, Topsail Island, Lea-Hutaff Island, Pleasure Island, Bald Head Island, Oak Island, and Holden Beach (78 FR 18000).

Fuentes et al. (2011) outlined sixteen adaptation strategies coastal areas can employ to mitigate the impacts of sea level rise on the terrestrial reproductive phase of sea turtles (Appendix A). Using specific criteria for choosing the most feasible strategies, Fuentes et al. (2012) suggested identifying and protecting areas that may be suitable nesting sites in the future. Investing in policies and legislation designed to protect beaches will not only have positive benefits for sea turtles and other beach-dwelling biota, but also for the North Carolina tourism industry, coastal landowners, and the general public. The original intent of this report was to analyze all sixteen strategies, but as my research and conversations with stakeholders progressed I quickly realized one strategy stood out among the rest: beach nourishment.

Beach nourishment – also called beach replenishment, renourishment, or beach fill – is the favored erosion control strategy in North Carolina. Beach nourishment is a “soft” approach to erosion control and does not use “hard” engineering structures such as breakwaters or groins. “Soft” alternatives are preferred for North Carolina shoreline management because they do not severely alter the natural geomorphic and hydraulic processes in the littoral zone. The three main types of nourishment projects in North Carolina include: dredged material disposal; storm protection; and habitat restoration (Limber and Warren 2006).

Most of North Carolina’s barrier islands were developed in the 1960s to 1980s during a 30-year lull in major hurricane activity. When Hurricanes Bertha, Fran, Bonnie, Dennis, and Floyd hit in the 1990s, nourishment activity was swift, responsive, and haphazard (GL Rudolph, personal communication, November 6, 2013). At the time, these mostly federally-funded nourishment projects were town-specific, with little consideration of the long-term or ecosystem-wide impacts. With advances in engineering and research on the impacts of nourishment, coastal managers are now trying to streamline the process and account for more variables, including sea level rise and sea turtle nesting.

Due to the economic value of coastal property and the ban on hard engineering structures on North Carolina beaches, beach nourishment is seen as an accepted engineering solution to combat shoreline erosion (Brock et al. 2009). Nourishment can have many recreational and economic benefits, but also carries several costs to both humans and sea turtles (Steinitz et al. 1998). The Program for the Study of Developed Shorelines at Western Carolina University estimates a total \$617,223,415 has been spent to date on beach nourishment in North Carolina (PSDS 2013). Despite the lofty price, nourishment is favored by influential beachfront property owners and by coastal counties and municipalities who depend on occupancy tax and property tax revenues from tourists and coastal property owners who value a wide, sandy beach.

Using hedonic property value models to estimate the loss of property value in Carteret and New Hanover Counties under different sea level rise scenarios, Bin et al. (2007) estimated a loss of \$30-\$170 million if sea levels rise 0.52 feet (0.16m) by 2030, and \$110-\$650 million if levels rise 1.51 feet (0.45m) by 2080. For the entire state, the North Carolina Beach and Inlet Management Plan (BIMP) Section IV analysis estimated a total economic loss of \$408 million if there were a 50 percent loss of all state beaches (2011, pg. IV-49). This scenario is not likely to happen, given the enormous investments by wealthy and influential coastal landowners to protect beachfront property and thereby the beach commons, but the enormous incentive to protect the beach (and the property behind it) is worth noting. With the state prioritizing nourishment as a viable and effective option to protect beaches, it is important that care be taken during the permitting process. Nourishment should not be viewed as a beach protection strategy necessarily unfavorable for sea turtles (Crain et al. 1995). In fact in North Carolina, there are already sediment criteria rules, environmental windows, and a series of safeguards in place to help avoid negative impacts on the biota. Even with these safeguards, however, there is still ample room for improvement.

In 2000, the United States Geological Survey (USGS) released the Coastal Vulnerability Index (CVI) – a national assessment of coastal vulnerability to sea level rise. In an effort to help policy makers and managers prioritize areas which will need the greatest conservation attention, Von Holle et al. (2014, in progress) investigated the effects of sea level rise on nesting sea turtles from North Carolina to Florida. Mapping the CVI alongside known nesting distributions in the South Atlantic, Von Holle et al. (2014, in progress) created habitat suitability maps for nesting sea turtles, including the loggerheads that nest on North Carolina beaches. This information is not yet published, but the lead on this project allowed me to use the unpublished maps to determine where to focus my research (see Appendix B). A detailed discussion of climate change, historic sea level change, current sea level rise trends, and future rate predictions, is beyond the scope of this report. See Bin et al. (2007), Kartinkov et al. (2008), and the 2011 North Carolina Beach and Inlet Management Plan Final Report (BIMP) for further discussion on the economic impact of sea level rise on North Carolina.

For my analysis, I chose to focus on beaches in Carteret, New Hanover, and Brunswick Counties in the southern half of North Carolina. These counties were chosen for four reasons: 1) high human population density in the developed beach areas; 2) vulnerability to sea level rise based on the USGS CVI (see Appendix B); 3) the existence of nesting loggerhead sea turtles (see Appendix C); and 4) each county contains proposed terrestrial critical habitat (see Appendix D). The beaches under the jurisdiction of Marine Corps Base Camp Lejeune from Bear Inlet to New River Inlet were not included

(Onslow County). Also omitted were Figure Eight Island, Wrightsville Beach, and Masonboro Island, because these areas were not proposed critical habitat for loggerhead sea turtles. Given the relatively low CVI ranking of Bear Island, Topsail Island, and Lea-Hutaff Island, I chose to also exclude these areas from the economic analysis. In my final economic analysis, I focus exclusively on Bogue Banks (Carteret County), Pleasure Island (New Hanover County), and Bald Head Island, Oak Island, and Holden Beach (Brunswick County). In 2013 there were a reported 1,246 loggerhead nests in the state, with 456 (36.6%) of those occurring in these five areas (WRC 2013).

Background

Loggerhead Nesting Biology

There are seven species of sea turtles worldwide. Four species – loggerhead, green, leatherback, and Kemp’s ridley – are commonly seen in the waters of North Carolina. This paper focuses exclusively on the loggerhead sea turtle (*Caretta caretta*), the species most likely to be seen nesting on North Carolina beaches. To gain a thorough understanding of loggerhead nesting biology and historical nesting patterns, I worked with Matthew Godfrey, the state sea turtle biologist with the North Carolina Wildlife Resources Commission (WRC). I also conducted a literature search to gauge the previous work done to understand loggerhead nesting.

In North Carolina, nesting occurs in the summer months, generally between May and October. These months coincide with peak tourism season, increased boating and beach activity, and hurricanes. Female loggerhead turtles nest on average every 2.5 to 3.7 years (Richardson et al. 1978; Bjorndal et al. 1983) and tend to lay 3-6 clutches of eggs per season (Frazer and Richardson 1985; Hawkes et al. 2005), depositing an average of 100 to 126 eggs in each nest (Dodd 1988). However, hatchling sea turtles have very high mortality rates (Crowder et al. 1994). Threats to hatchling survival include, but are not limited to predation, marine debris ingestion and entanglement, illegal harvesting of eggs, and human impacts on sea turtle nesting sites (STC 2013). Sea level rise “may cause loss and/or alteration of nesting beaches and egg mortality” (Fuentes et al. 2010, pg. 140).

Loggerheads in North Carolina generally show high nest site fidelity (Miller et al. 2003) but it is unknown why a female chooses a particular nesting site over another. “False crawls” occur when a female leaves the water, begins to crawl onto the beach – presumably to select a nesting site – but, perhaps due to unfavorable nesting conditions or disturbance, she returns to the water without nesting. Factors possibly affecting nest site selection include beach length, width, height, slope, orientation,

and/or vegetation (Mortimer 1990). Given that females tend to return to the same nesting area in which they hatched, loss and/or modification of these nesting beaches due to sea level rise and/or human disturbance may have an impact on future loggerhead demography.

Sea turtles exhibit temperature-dependent sex determination (TSD), with cooler sand tending to yield males and warmer sand tending to yield females (Yntema & Mrosovsky 1980; Wibbels 2003). Sex is determined by sand temperature during the middle third of the incubation period (Mrosovsky & Pieau 1991). Many studies (Hawkes et al. 2007; Mrosovsky & Godfrey 2010; Fuentes and Cinner 2010; Fuentes et al. 2010) cite increasing temperature – and the correlating skewed sex ratio of females to males – as the most detrimental aspect of climate change to sea turtles. However, Fuentes et al. (2012) points out that in areas with cooler nest depth temperatures, and therefore areas likely to produce more male hatchlings, mitigating the impacts of sea level rise is of “of greater relative importance than mitigating the impacts of increases in temperature on nesting grounds” (Fuentes et al. 2012, pg. 59). North Carolina is one of those areas, as it is at the northern limit of nesting for the Northwest Atlantic Ocean Loggerhead Sea Turtle DPS.

Sea level rise is as a major concern for sea turtle survival because of the possible loss of nesting habitat (Fish et al. 2005; Hawkes et al. 2007; Fish et al. 2008). Sea turtles have survived climatic variations in the past (Hamann et al. 2007) but the rate at which sea levels are rising poses a threat that they have not yet faced. Coastal development, beachfront structures, beach driving, and nourishment projects all impact nesting habitat. The ability of sea turtles to adapt will depend, in part, on effective conservation and management strategies (Hamann et al. 2010).

Sea Turtle Management in North Carolina

Sea turtle management in North Carolina is complex and involves several federal and state agencies that differ in their management jurisdiction and philosophy (McClellan et al. 2011). Further complicating management is the recent proposal to list critical habitats under the Endangered Species Act. Sea turtles have been listed as threatened throughout their range under the ESA since 1978 (43 FR 32800). Under the ESA, the NMFS and FWS were assigned joint jurisdiction over the threatened and endangered species at the federal level. Pursuant to a joint memorandum of understanding, the NMFS has responsibility to manage sea turtles in the marine environment while the FWS is responsible for the protection of sea turtles on land – during nesting, incubation, and hatching. Both the FWS and NMFS are responsible for protecting sea turtles from anthropogenic stressors, such as dredging, nourishment

projects, shoreline armoring, artificial lighting, and other threats to nesting habitat (McClellan et al. 2011).

Despite being given the authority and responsibility to protect loggerheads under the ESA, critical habitats were not established upon their initial listing in 1978 (43 *FR* 32800). Decades later, in 2007, the Center for Biological Diversity, the Turtle Island Restoration Network, and Oceana petitioned requests for the loggerhead to be reclassified into distinct population segments (DPSs) and for critical habitats to be designated (NOAA 2011; NMFS 2013). The NMFS and FWS created a Recovery Team charged with drafting a Recovery Plan for the Northwest Atlantic DPS (NMFS and FWS 2008). In this Recovery Plan, the loggerhead sea turtles in Virginia, North Carolina, South Carolina, and Georgia were identified as part of the Northern Recovery Unit. Then, in September 2011, the NMFS and FWS jointly issued a rule that modified the ESA listing from one global population to nine DPSs of loggerhead sea turtles (76 *FR* 58868). Loggerhead sea turtles in North Carolina are part of the Northwest Atlantic Ocean DPS and designated as threatened (76 *FR* 58868).

The Northern Recovery Unit of loggerheads is particularly important to conservation efforts because these loggerheads are genetically distinct from other Recovery Units in the southeast United States (NMFS and FWS 2008). North Carolina is also slightly buffered from similar climate variations seen in the rest of the Northern Hemisphere due to its proximity to the Gulf Stream (Hawkes et al. 2007). Because sand temperatures are inherently cooler in North Carolina, South Carolina, and Georgia than in Florida, this northern subpopulation produces a greater number of males that then are able to interbreed with the females from the other populations (Hawkes et al. 2007). Based on 26 years of data, Hawkes et al. (2007) found that North Carolina beaches produce 42% male hatchlings, whereas beaches in Florida only produce around 10% males.

As per the ESA, recovery plans and critical habitat must be designated and implemented by the NMFS and the FWS within one year of listing. The FWS and the NMFS submitted separate proposals for critical habitats (terrestrial environment and marine environment) in March 2013 and July 2013, respectively (78 *FR* 18000; 78 *FR* 43005). The final terrestrial and in-water critical habitat rulemaking document is expected in July 2014 (FWS 2013; 78 *FR* 42921). These critical habitat designations are relevant to this study, as they may impact the ability of coastal communities to obtain federal permits for beach protection projects.

Under Section 6 of the ESA, the NMFS and the FWS have the opportunity to create cooperative agreements ("Section 6 agreements") with state agencies to protect listed species such as sea turtles (McClellan et al. 2011). These cooperative agreements are an avenue by which funding is allocated to

states for endangered and threatened species protection. In North Carolina, the state agency with Section 6 agreements for sea turtles with the NMFS and the FWS is the Wildlife Resources Commission (WRC). As per the Agreements, the WRC has the responsibility to comply with the ESA and support the recovery plans for sea turtles in North Carolina. As a result, the WRC has authority to manage nesting females, incubating eggs, and hatchlings (McClellan et al. 2011). While the WRC is critical for the management of sea turtles on land, the relationship between the NMFS, which holds authority over sea turtles in the water, and the state of North Carolina, is different. The cooperative agreement between the NMFS and the WRC is for the management of sick, injured, or dead sea turtles that strand on the ocean or estuarine coastline in North Carolina. All other in-water management falls completely within the jurisdiction of the NMFS. The North Carolina Division of Marine Fisheries (DMF) holds Section 10 permits with the NMFS to allow the incidental capture and mortality of sea turtles in state-managed fisheries (McClellan et al. 2011).

At the local level, volunteer groups are authorized by the WRC to conduct management activities with the sea turtles, such as protecting nests and assisting with inventories after nest emergence, in accordance with the ESA and recovery plan guidelines (MH Godfrey, personal communication, November 23, 2013). All activities at the state and local level are overseen by the FWS. Nearly all coastal municipalities are recognized as sea turtle sanctuaries, meaning they will uphold the state laws that protect sea turtles. As such, they are bound to reduce all activities that negatively impact or disturb sea turtles. This includes minimizing artificial lighting during nesting season, which has an impact on both nesting females and emerging hatchlings as beach lighting can misorient sea turtles.

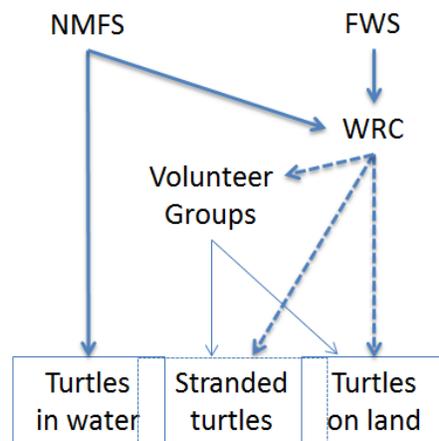


Figure 1. Sea turtle management structure in North Carolina. Flow chart of federal (bold solid line), state (dashed lines), and local (thin line) management entities and their management jurisdiction (boxes).

Management of North Carolina Beaches

Similar to the management network for sea turtles, the management of beach protection projects in North Carolina follows a complex structure, with federal, state, and local involvement. At the federal level, a multitude of agencies have the responsibility to protect areas from shoreline erosion and flooding, including: the U.S. Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA), and agencies within the U.S. Department of Interior, including NOAA, the US Geological Survey, and the Bureau of Ocean Energy Management.

The legal mandates that influence management of shoreline erosion are the various Water Resources Development Acts (WRDA), the Coastal Zone Management Act (CZMA), and Section 111 of the River and Harbor Act of 1968 (NOAA Coastal Services Center 2013). The WRDA gives the USACE authority to administer any water resource development project – which includes nourishment projects – while the River and Harbor Act of 1968 authorizes the USACE to participate in cost-sharing and construction of shoreline protection projects.

The CZMA requires all federal projects to be consistent with the approved state coastal zone management program, or the North Carolina Coastal Area Management Act (CAMA). When CAMA was adopted in 1974, the North Carolina General Assembly gave the Coastal Resources Commission (CRC) the authority to create rules for both CAMA and the North Carolina Dredge and Fill Act (DCM 2013), another law regulating beach fill projects in the state. In addition to rule-making, the CRC granted beach nourishment permitting authority to the Division of Coastal Management (DCM). DCM has the responsibility to coordinate with local and county governments, the state WRC, Division of Marine Fisheries, and Division of Water Quality, and the federal FWS, NOAA, and USACE, in order to minimize adverse environmental impacts and impacts to wildlife.

In addition to these legal mandates, there are laws regulating construction projects themselves. The USACE is given authority to construct, operate, and maintain projects, but also has responsibility to comply with Section 404 of the Clean Water Act (CWA) and the National Environmental Policy Act (NEPA) water quality guidelines. NEPA requires an Environmental Impact Statement (EIS) or Environmental Assessment (EA) for all major construction projects, which include beach nourishment and terminal groin construction. This environmental assessment is integrated into the USACE 6-step planning processes before construction begins. As per the CWA, Section 404 permits for coastal construction projects are coordinated through the USACE district office in Wilmington, North Carolina (USACE 2013).

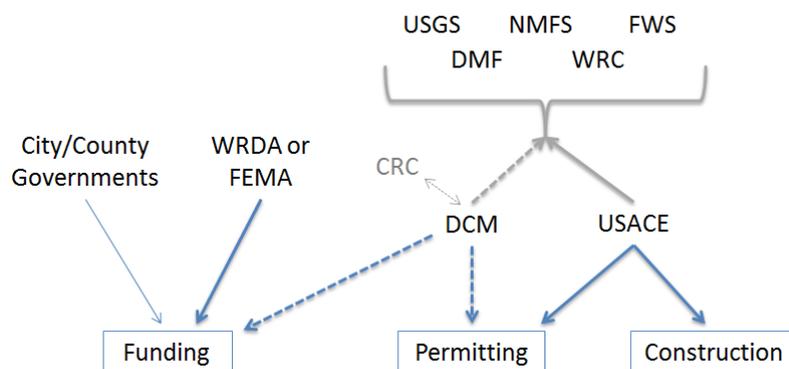


Figure 2. Beach protection management structure in North Carolina. Flow chart of federal (bold solid blue line), state (dashed blue lines), and local (thin blue line) management entities and their management jurisdiction (boxes). Grey lines represent coordination efforts between the listed agencies.

The management of sea turtles in North Carolina is complicated by several agencies with differing jurisdictions, but the laws and policies pertaining to beach nourishment are even more confusing. The fact that sea turtles are a threatened species under the ESA increases the difficulty in obtaining permits, because many agencies must coordinate to ensure the protection of critical habitat. Recent changes in North Carolina legislation add yet another layer of complexity to an already complicated management structure.

Sea Level Rise Planning in North Carolina

Beginning in the 2011-2012 Session, the North Carolina General Assembly began making changes to state legislation that facilitate coastal development and shoreline protection and make conservation and sea-level rise planning more challenging. In 2011, there was contention in the state over the rate at which sea-levels were rising after the 2010 CRC Science Panel released the “North Carolina Sea-Level Rise Assessment Report”, which recommended planning for 1 meter of sea-level rise (pg. 12). As a result of this controversy, House Bill 819/ Session Law 2012-202 prohibited any “rule, policy, or planning guideline that defines a rate of sea-level change” (HB 819 Section 2(a)). Additionally, the HB 819 states that “the General Assembly does not intend to mandate the development of sea-level policy” and that “the Commission shall be the only State agency authorized to define rates of sea-level change for regulatory purposes” (HB 819 Section 2(a)). Therefore, at the state-level, sea-level rise planning is neither required nor allowed. Finally, HB 819 Section 2(b) mandates that the State cannot define rates of sea-level rise until July 1, 2016. Section 2(c) of HB 819 mandates that the CRC Science Panel should create a follow-up “North Carolina Sea Level Rise Assessment Report” by March 31, 2015.

As of April 2014, the CRC had yet to designate new members to the Science Panel and there has been no official mention of the updated Sea-Level Rise Assessment Report.

The 2011-2012 Session also saw a change to the thirty-year ban on hardened structures on the North Carolina shoreline. Senate Bill 110, passed in 2011, allowed for up to four terminal groins to be considered for construction. Four permit applications have been submitted to the USACE for terminal groin construction projects at Holden Beach, Ocean Isle Beach, and Bald Head Island in Brunswick County, and Figure Eight Island in New Hanover County (NCCF 2013). Before any of these structures will be constructed, they must go through a series of environmental reviews, including a formal Environmental Impact Statement (EIS). None of the areas have completed this review process or applied for state permits yet. It should be noted that during the 2013-2014 Session, Senate Bill 151/Session Law 2013-384 (SB 151) was passed into law, which explicitly stated that plans are *not* required to address sea-level rise.

Also in the 2013-2014 Session, Senate Bill 402 – the 2013 Budget -- replaced all but four of the fifteen CRC Coastal Resources Commissioners, decreased the number of seats from fifteen to thirteen, and removed the dedicated conservation seat. This sweeping change is relevant because the CRC maintains the authority to create rules about sea-level rise planning in North Carolina (per HB 819). It is too early to know how the new members will prioritize sea-level rise planning, but much of the institutional knowledge about the 2010 CRC Science Panel's "North Carolina Sea-Level Rise Assessment Report" has been lost with the reorganization of the CRC.

Other Relevant Stakeholders

In coastal North Carolina, the key players are coastal residents, property owners, and tourists, as well as development interests, coastal business owners, and municipalities. Oceanfront property owners tend to have the most interest in beach protection, because their property is directly impacted by nourishment or the construction of hard engineered structures, such as terminal groins. Additionally, oceanfront property owners pay increased property taxes; of which a portion goes toward financing these beach protection projects (GL Rudolph, personal communication, November 6, 2013). The local town governments and county commissions are instrumental to the process if local residents push for a nourishment project or engineered structure to protect their beachfront property (Annabelle 2010a).

NC-20, a partnership that supports economic development in the 20 North Carolina coastal counties, is another major stakeholder (NC-20 2013). This organization was the driving force encouraging the watering-down of language in the 2010 Sea-Level Rise Assessment Report and was

instrumental to the final passage of HB 819. NC-20 will almost certainly continue to lead lobbying efforts against adopting a rate of accelerated sea level rise, as suggested by the first Sea-Level Rise Assessment Report.

Other major stakeholders I worked directly with on this project include the Carteret County and New Hanover County Shore Protection Managers, Greg (Rudi) Rudolph and Layton Bedsole, respectively. Their initiatives may be directly impacted by my conclusions, should the state choose to consider any of my recommendations. Organizations like the Carteret County Shore Protection Office play a key role lobbying legislatures, taxpayers, and county and municipal governments to secure funding for nourishment projects (Annabelle 2010a).

Matthew Godfrey, the Wildlife Resources Commission sea turtle biologist, is also a key stakeholder, as his work focuses on sea turtle protection within the state. Additionally, there are 21 sea turtle volunteer groups across the state (NC Sea Turtle Project 2013), contributing the annual equivalent of approximately \$630,000 in volunteer labor to monitor and protect nesting beaches and hatchlings (MH Godfrey, personal communication, December 4, 2013). These volunteer groups have been given the authority to manage nesting sea turtles and hatchlings under the WRC, and they have had a tremendous impact on both the protection and the public perception of the species.

Public perception of sea turtles, beach nourishment, and sea level rise are central factors influencing this issue. Tourists, for example, are major players on the coast – the domestic tourism industry in Carteret, New Hanover, and Brunswick counties generated \$1.187 billion in revenue in 2012 (Department of Commerce 2013). Undoubtedly, tourists visit the North Carolina coast mostly for the beaches. If beaches erode, then tourism, and its associated revenue, suffers. Beach protection itself stems from the desire of individuals or municipalities desires to protect the beach. The public's willingness or desire to protect sea turtles should also be considered, as some tourists come to North Carolina specifically with the hope of seeing a nesting loggerhead sea turtle. Delgadillo (2012) conducted public interviews during the summer of 2012 and estimated that the presence of sea turtles on Bald Head Island resulted in a total value of \$49 million, and that turtle eco-tourism could generate \$33 million for Bald Head Island annually.

Summary of Findings

Historical North Carolina Nourishment Projects

Traditionally, beach nourishment has been used to combat intermediate-term efforts like beach erosion and natural shoreline dynamics. Beach protection projects in North Carolina consistently begin at the local level. Each project is initiated by the desire of a coastal county or municipality to protect their beaches. Once an area decides to pursue a nourishment project, cost-sharing is almost always required between federal, state, and local governments. The local governments have an instrumental role in acquiring funding for these projects via bonds and taxation. While the issuance of bonds is the main local funding source, each county and some municipalities have an occupancy tax that generates a portion of local funding, in addition to taxation revenues from oceanfront private property (GL Rudolph, personal communication, November 6, 2013).

Bin et al. (2007) estimated the loss of property value in Carteret and New Hanover Counties under different sea level rise scenarios. According to this study, Carteret County could see losses from 1% to 3% depending on the amount sea levels rise (0.36 feet to 2.66 feet, respectively). New Hanover County is estimated to lose about one percent of its total coastal property value by 2080 (BIMP 2011, pg. IV-4).

From 1950-1993 annual renourishment project costs averaged \$3.4 million, but since the mid-1990s as demand for nourishment projects grew, costs increased up to \$100 million annually (BIMP 2011, pg. IV-7). More recently, due to federal budget cuts, there is a shift away from relying on federal funding and towards entirely locally-funded projects. Carteret County in particular is looking at ways they can secure long-term local funding for beach nourishment (GL Rudolph, personal communication, November 6, 2013).

For my analysis, I obtained historic beach nourishment data from both the North Carolina Division of Coastal Management (DCM) and the Program for the Study of Developed Shorelines at Western Carolina University (PSDS). I cross-checked the databases to eliminate discrepancies and, after speaking with the database managers at both organizations, determined that the PSDS database is the most up-to-date and complete dataset to use for my analysis.

I first sorted the nourishment data by county and beach. The database had nourishment information through 2013, but costs were in 2012 dollars. However, for Carteret County only 63% of the projects listed in the database listed total project costs. In New Hanover County only 59% listed costs, and in Brunswick County 68% listed costs. Unable to do a complete analysis with a half to a third of the

data missing, I chose to estimate total project costs in 2014 dollars (\$) by using the Consumer Price Index (CPI) conversion factors and a series of interpolations.

For each project that already listed cost, I estimated the cost of each project in 2014\$ using the CPI conversion factor for that year. Once I had a total cost estimate for each project in 2014\$, I calculated the 2014\$ cost per cubic yard of sand. Next, I found the average cost per cubic yard for all the beaches within each county using the volume of sand placed as the denominator. Using this average cost per cubic yard, I was able to then interpolate the cost of projects that did not originally have a cost listed. For example, given that the average cost per cubic yard in New Hanover County is \$6.11, I used that average to estimate the total cost of each project of which there is a record of the cubic yardage but not of cost (91% of the projects in New Hanover County had volume listed but only 59% listed project cost). As an example, the PSDS database showed that in 1996, 3,500,000 cubic yards of sand were placed on Carolina Beach in New Hanover County, but there is no record of the cost of that project. If the average cost per cubic yard is \$6.11 (2014\$), then I estimated the total cost of that rather large project to be \$21,385,000 (2014\$).

County	Years	Total Volume Placed (cy)	Previously Estimated Total Cost	My Estimated Total Cost to Date	Average Cost per Cubic Yard	Average Cost per Project
Carteret	1958-2013	27,346,801	\$186,258,631	\$200,385,767	\$13.25	\$4,554,222
New Hanover	1955-2013	26,903,664	\$129,212,589	\$159,281,036	\$6.11	\$3,792,406
Brunswick	1971-2013	23,321,059	\$129,688,491	\$175,481,842	\$6.91	\$2,830,352

Table 1. This table summarizes all of the completed beach nourishment projects on Carteret, New Hanover, and Brunswick counties to date. All costs are in 2014 USD. There have been total 148 projects in these three counties, with an estimated total cost of \$535,148,645. The Total Costs without Interpolation are the original estimated costs of nourishment, but did not take into account 66% of the projects since cost was not listed in the database. Areas included in the Carteret County analysis: Fort Macon State Park, Atlantic Beach, Pine Knoll Shores, Indian Beach/Salter Path, Emerald Isle. Areas included in the New Hanover analysis: Carolina Beach, Kure Beach. Fort Fisher State Recreation Area was excluded from this analysis as there is no record of beach nourishment within the SRA boundaries. Areas included in the Brunswick County analysis: Bald Head Island, Caswell Beach, Oak Island, Holden Beach.

To the best of my knowledge, Table 1 represents the most comprehensive estimate of the total cost of beach nourishment in Carteret, New Hanover, and Brunswick Counties to date. The PSDS “Beach Nourishment Viewer” (<http://beachnourishment.psdw-wcu.org/results.php?state=NC>) grossly underestimates total costs across the state since only 34% of the 274 projects between 1939 and 2013

actually list project cost. These three counties alone have spent the equivalent of \$535 million on beach nourishment since 1955. Since 1939, only 1 of the total 274 beach nourishment projects was specifically for “sea turtle habitat restoration” – this project occurred in 2001 on Oak Island and placed 2,650,000 cubic yards of incompatible sand on the beach at a cost of \$8,509,669 (DCM 2008).

Historical Loggerhead Nesting in North Carolina

Since 2000, there have been 10,882 loggerhead sea turtle nests laid on North Carolina beaches. 7,106 (65.3%) of those nests were laid between Bogue Banks and the South Carolina border – the southern beaches identified in the critical habitat proposal. 4,082 (37.5% of the total) nests occurred on the beaches within my study area (see Table 2).

Beach	Length (km)	Avg Nests per Year	Nest Density	Avg False Crawls per Year	False Crawl Density	Nest to False Crawl Ratio
Fort Macon State Park	1.70	3.00	1.76	1.00	0.59	3 : 1
Atlantic Beach	8.10	3.64	0.45	4.18	0.52	0.87 : 1
Pine Knoll Shores	7.50	5.62	0.75	6.08	0.81	1 : 1
Indian Beach/Salter Path	3.90	4.00	1.03	2.08	0.53	1.92 : 1
Emerald Isle	18.00	16.86	0.94	10.93	0.61	1.54 : 1
Carolina Beach	6.44	7.79	1.21	4.07	0.63	1.91 : 1
Kure Beach	4.83	9.21	1.91	5.64	1.17	1.63 : 1
Fort Fisher SRA	4.83	24.07	4.99	28.43	5.89	0.85 : 1
Bald Head Island	14.48	70.00	4.83	94.85	6.55	0.79 : 1
Caswell Beach	4.83	50.64	10.49	44.00	9.11	1.15 : 1
Oak Island	16.09	63.93	3.97	43.29	2.69	1.47 : 1
Holden Beach	11.27	34.57	3.07	30.43	2.70	1.14 : 1

Table 2. Beaches listed are areas currently proposed as critical nesting habitat for the loggerhead sea turtle. In terms of count, Bald Head Island and Oak Island see the greatest number of nests per year, but Caswell Beach sees the greatest density of nesting (10.49 nests per kilometer). Areas with the greatest nesting density also have the greatest false crawl density. Thick blue lines separate beaches by county, with beaches listed north to south in Carteret County, then New Hanover County, then Brunswick County.

Fort Fisher State Recreation Area, Bald Head Island, and Caswell Beach support the three highest nesting densities in the state (See Appendix B) with Caswell Beach far exceeding others with an average 10.49 nests per kilometer. Atlantic Beach, Fort Fisher SRA, and Bald Head Island average more false crawls than confirmed nests (0.87; 0.85; 0.79:1, respectively) while Emerald Isle, Carolina Beach, and Kure Beach averaged almost two confirmed nests to one false crawl from the years 2000-2013 (1.54; 1.91; 1.63:1, respectively).

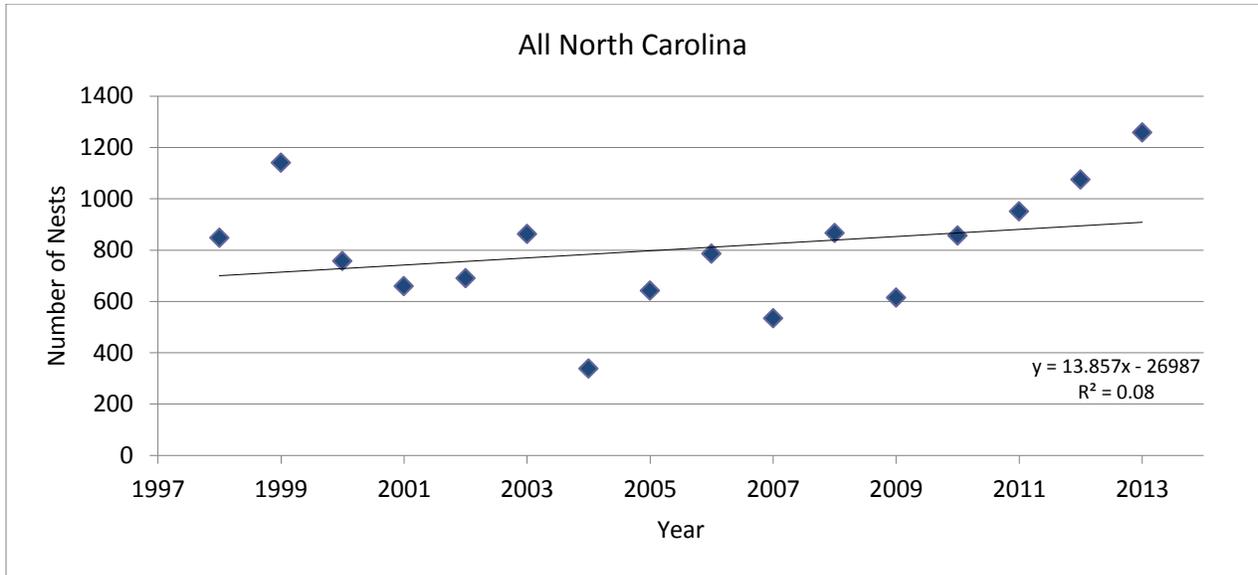


Figure 3. Number of nests occurring within the entire state of North Carolina from 1998 to 2013. See Appendix E for individual beach regressions. Nesting data obtained through the North Carolina WRC.

In the entire state, nesting is increasing steadily (see Figure 3 – see Appendix E for regressions of individual beaches). One caveat to this assertion is that the amount of volunteer effort spent searching for loggerhead nests and false crawls has also increased. If more volunteers are scouring the beaches searching for turtle tracks, it is likely that more tracks are being counted. For example, Atlantic Beach has only had a consistent volunteer nest-monitoring group since 2003, the Atlantic Beach Sea Turtle Patrol. Other beaches in the state, such as Masonboro and Lea-Huttag Islands, have also had variation in monitoring effort. Future studies should attempt to control for changes in monitoring effort, as it may bias estimates of the number of loggerhead sea turtle nests. It is also entirely plausible, however, that the population is, in fact, recovering – the ultimate aim of the Endangered Species Act. Because of these unknowns, and because this is an ESA listed species, it is vital to understand how beach construction, manipulation, and other aspects of nourishment impact loggerhead sea turtle nesting.

Impacts of Nourishment on Nesting

The Economic Analysis for Loggerhead Proposed Terrestrial Critical Habitat produced by Industrial Economics, Inc. (2013) includes “in-water and coastal construction” and “sand placement” as key activities that may have an impact on loggerhead critical habitat. The use of heavy construction equipment – such as bulldozers and pipelines – can compact the placed sediments, making conditions unsuitable for nest digging. Additionally, dredge equipment in the water can accidentally kill or injure sea turtles. Under Section 3(18) of the ESA, any dredge action that would “harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct” is considered a take. In North Carolina, the USACE administered a National Marine Fisheries Biological Opinion in 2007 that all civil works and regulatory projects must operate under (G.L. Rudolph, personal communication March 10, 2014). The Biological Opinion sets incidental take limits and provides environmental windows during which construction projects may occur. In North Carolina, either hopper dredging or pipeline dredging may be used to transport borrow sand onto the receiving beach. For hopper dredges, the environmental window is January 1 to March 31 of every year; for pipeline dredges, the window is November 15 to April 30 (G.L. Rudolph, personal communication March 10, 2014). Under certain situations, these windows are sometimes not adhered to and construction continues into loggerhead nesting season.

A Web of Science and Google Scholar literature review revealed there are no published studies of the impacts of beach nourishment specifically on North Carolina loggerhead sea turtle nesting. Most studies to date have focused on Florida or South Carolina and draw negative correlations between nesting success and nourished beaches (Steinitz et al. 1998; Rumbold et al. 2001; Dean 2002; Byrd 2004; Brock et al. 2009; Long et al. 2011). However, others point out that nourishment may create beach nesting habitat that would otherwise be unavailable (Crain et al. 1995).

During a seven-year study on Jupiter Island, Florida, Steinitz et al. (1998) found sea turtle nesting decreased in the nesting seasons immediately following beach nourishment. Their analysis also revealed a greater frequency of false crawls in the year after nourishment, perhaps due to overly compacted sand and construction berms that make it difficult for a female to dig or to navigate the nesting beach. They found that it took two years – the third nesting season – for nesting success on the nourished beach to be statistically the same as the control beach (without nourishment), although it took only one year for the beach profile to stabilize. Lund (1986) was the first to capture the idea that it takes one to two years for a beach profile to stabilize. There seems to be a lag of about one year between when a profile equilibrates and when nesting success rebounds.

Rumbold et al. (2001) also found that loggerhead nesting success decreased in the first year after nourishment on Jupiter Island, Florida, but then bounced back the second year. Likewise, false crawls increased on the nourished beach the first year after nourishment, but remained at approximately a 1:1 ratio on the unnourished control beach. The decreased nesting success and increased false crawl-to-nest ratio suggests a negative impact on loggerhead nesting the season immediately following nourishment construction.

Byrd (2004) conducted an analysis in South Carolina and found that “beach nourishment has the potential to significantly affect loggerhead sea turtle nesting”(pg. 45) but that the effects varied among different beaches in her study site. Brock et al. (2009) also found a decreased loggerhead nesting in the first year immediately following nourishment and that an altered beach profile in Florida was the likely cause. Physical attributes of the nourishment material did not seem to hinder nesting. Their conclusion came as a result of the increase in loggerhead nesting two seasons post-nourishment.

The greatest concern regarding the effects of beach renourishment stem from an altered shoreline profile and particularly from the existence of a scarp that can hinder the ability of nesting females to move into areas of preferred nesting conditions (Dean 2002). Long et al. (2011) used LiDAR imaging to study a hurricane-impacted Florida beach and subsequent restoration to see how sea turtle nesting success was impacted before and after alteration. Their multiple regression models revealed that slope, volume, and beach profile may be the most significant variables prompting loggerheads to select a certain nesting site. Their most notable finding was that a change in the beach profile was negatively correlated with loggerhead nesting success, suggesting that beach profile is a key driver in nest site selection.

When the USACE nourishes a beach, they build a “constructed berm” that extends the shoreline profile seaward (see Figure 4), but they do not manipulate the new profile to recreate the original profile. The “design profile” is what the constructed berm is supposed to equilibrate to. It is assumed that over time – usually 1 year – the profile will adjust naturally to look more like the design profile. The studies in Florida suggest the lag between completed construction and corrected profile may be negatively influencing loggerhead sea turtle nesting (Brock et al. 2002). Depending on how close the end of the construction is to nesting season, this lag may delay or deter some nesting approaches. If a female does successfully nest close to the shoreline on the newly constructed berm, there is a risk of the nest washing out as the profile equilibrates.

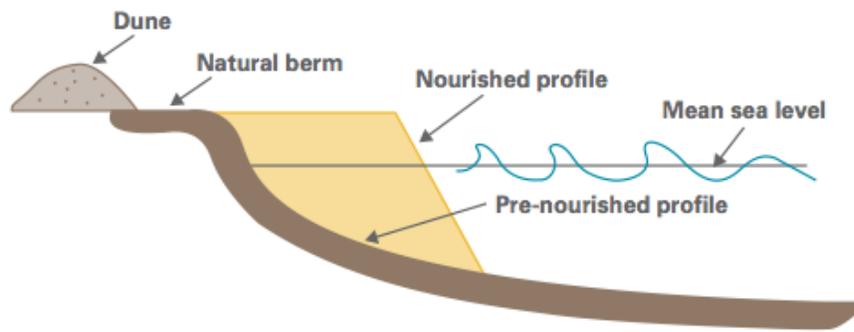


Figure 4. Taken from ASBPA Shore Protection Assessment on Beach Nourishment: How Beach Nourishment Works (2007). This image shows the typical post-construction nourished profile in relation to the pre-nourished profile. The nourished profile is much more abruptly sloped and may deter nesting female loggerhead sea turtles.

Other concerns for the impacts of nourishment on sea turtle nesting include the quality of sand placed on the beach. DCM has addressed most of these issues with the adoption of the Sediment Criteria Rules on February 1, 2007. These rules mostly focus on sediment size, to avoid placing overly coarse or fine sand onto the recipient beach. To determine compatibility, the rule requires at least five transects to occur along the native beach, with twelve sediment samples taken along each transect. There is one major, and possibly critical, exception to this rule however; sediment borrowed from regularly maintained navigation channels does not require sampling. It is assumed that this sediment originated from the native beach and is therefore compatible. Rules for sampling the borrow sediment include sonar and bathymetric imaging, and evenly-spaced core sampling (Limber and Warren 2006). Again, the exception to this rule is sand borrowed from navigation channels, where fewer cores must be taken and no imaging is necessary.

Through my research I developed concerns about the toxicity, color, and quality of sand that has been dredged from harbors and inlets. Harbors, channels, and inlets are the source of material for the majority of North Carolina's nourishment projects. These areas are sinks for contaminants and toxins. Placing this material on the beach can over time have an effect on sea turtle survival (Crain et al. 1995). Originally this sand may have been on a beach and washed out into the harbor or inlet, but after continued exposure to boat traffic and runoff pollution there is a chance that this sand is of poorer quality than that which originated on the beach. If there is a continued effort to take the same sand from the same heavily used harbor or inlet area and pump it onto the same beach upon which it eroded from, logic might conclude this sand is of lesser and lesser quality.

It is also important to note that the Sediment Criteria Rules do not specify sediment color as criteria. This may be a critical neglect on the part of the state, especially with water and air temperatures already increasing as a result of climate change. As mentioned before, loggerhead sea turtles exhibit TDS, meaning their sex is determined in the middle third of the incubation period (Mrosovsky & Pieau 1991). It has been found that nests incubated on darker (warmer) beaches will produce almost exclusively females, while nests incubated on lighter beaches tend to have a mix of males and females (Yntema & Mrosovsky 1980; Wibbels 2003). The USACE also does not use a color chart or specific rules to define sediment compatibility, but they do attempt to match new sediment to the native beach (Limber and Warren 2006). See Figure 5 for a comparison between the USACE Federal Standards and the North Carolina Sediment Criteria Rules.

		USACE	North Carolina
Native Beach	Characterization required?	YES	YES
	Beach transect spacing	5,000 ft.	5,000 ft.
	Beach profile sampling	Active beach profile sampled from dune toe to offshore bar; more offshore samples than onshore	≥12 samples along active beach profile at specific morphodynamic zones; half offshore & half onshore
Borrow Site	Bathymetric imaging	YES; variable coverage	YES; 100% coverage
	Subsurface seismic profiling	YES; variable line spacing	YES; 1,000 ft line spacing
	Core density	1,000 ft grid spacing	1,000 ft grid spacing
Sediment Compatibility	Determination of sediment compatibility	Overfill factors (R_A) ¹ ; fine sediment may not exceed 10%	Grain size thresholds (“Fine”, “Granular”, and “Gravel”) tied to native beach (Figure 4)
	Carbonate content allowable	Unspecified	≤15% above native content

Figure 5. Taken from Limber and Warren (2006). Comparison of North Carolina Sediment Criteria Rules and the USACE Federal Standards for beach fill sediment.

The 2013 Review of Biological and Biophysical Impacts from Dredging and Handling of Offshore Sand produced by the Bureau of Ocean Energy Management (Michel et al. 2013) reported that impacts from dredge activities in the water that could potentially affect loggerheads include: sound, increased sedimentation and turbidity, water quality, changes to the borrow site, and direct interactions with the dredge vessel. The report estimates that the sea turtle “take” rate is one turtle per 3.8 million cubic yards of dredged sand. To mitigate a “take”, the USACE implemented national protection methods in

1992 that include: adhering to dredging windows for certain dredge types and locations; requiring dredges to have drag head turtle deflectors; and observer efforts to capture and relocate any sea turtles seen in the vicinity. However, the USACE South Atlantic Division Regional Biological Opinion did not set environmental window restrictions on the use of hopper dredges in North Carolina (Michel et al. 2013, pg 4-121). While the USACE does not set restrictions, permits for dredging and nourishment must still be obtained from the state Division of Coastal Management, which requires that:

In order to protect threatened or endangered species and to minimize adverse impacts to offshore, nearshore, intertidal and beach resources, no excavation or beach nourishment activities shall occur from April 1 to November 15 of any year without prior approval from the Division of Coastal Management in consultation with the Division of Marine Fisheries, the North Carolina Wildlife Resources Commission, and the US Army Corps of Engineers (Permit Number 86-12 for dredging and nourishment of Emerald Isle to Pine Knoll Shores, pg. 1).

Additionally, the state permit requires the dredge operate to immediately cease operation for any of the following scenarios: 1) if the sand is deemed non-compatible; 2) if a turtle crawl or nest is identified within the nourishment area; 3) if there is an incidental take of a sea turtle by the dredge. State permits also require monitoring of beach compaction and escarpments for the next three nesting seasons immediately following completion of the nourishment project.

Discussion and Recommendations

The North Carolina BIMP Final Report calculated the socio-economic value of North Carolina beaches and inlets to recreationists (2011, IV-13). These "Beach Recreation Annual Direct Expenditures" estimate the total amount spent by visitors within each county/beach. Table 3 summarizes both the 2011 BIMP data and my 2014 analysis. If the average cost of a project in Carteret County is \$4,554,222, there would have to be 524 projects each year to equal the same amount of revenue brought into the county by way of beach recreation. Of course not all of the annual direct expenditures are retained by the county/beach, and only a small portion of tax revenues (3.6% of the Tourism Occupancy Tax) goes directly to funding beach nourishment. However, given that wide, sandy, stable beaches are a prerequisite for the beach recreation and tourism industries, there are clear economic incentives for protecting North Carolina beaches.

County	Beach	Beach Recreation Annual Direct Expenditures	Average Cost Per Nourishment Project
Carteret		\$238,730,493	\$4,554,222
	Fort Macon SP	\$5,154,950	
	Atlantic Beach	\$49,558,267	
	Pine Knoll Shores	\$18,836,295	
	Indian Beach/Salter Path	\$11,010,834	
	Emerald Isle	\$128,693,187	
New Hanover		\$169,813,929	\$3,792,406
	Figure Eight Island*	No Data	
	Wrightsville Beach*	\$104,128,871	
	Masonboro Island*	No Data	
	Carolina Beach	\$50,602,615	
	Kure Beach	\$15,082,444	
	Fort Fisher SRA	Included in Kure Beach	
Brunswick		\$203,546,079	\$2,830,352
	Bald Head Island	\$18,064,623	
	Oak Island (Includes Caswell Beach)	\$38,546,230	
	Holden Beach	\$55,990,520	
	Ocean Isle*	\$55,622,777	
	Sunset Beach/Bird Island*	\$35,133,558	

Table 3. Summarizes the annual direct expenditures on beach recreation for each county and beach in my study area and compares these values to the average cost of a beach nourishment project. All data is in 2014\$. Items followed by an * are not included in my study area and therefore do not contribute to the average cost of beach nourishment figures. I included these beaches only to show where each of the total counties' expenditures are generated.

Orrin Pilkey suggests that the only long-term solution to sea level rise and shoreline change is strategic retreat (Pilkey 2012). Immediate retreat is unfortunately not seen as a viable option for many wealthy and influential beachfront property owners. Retreat is only an alternative in undeveloped barrier island areas, such as Shackleford Banks, Bear Island, and Masonboro Island that are allowed to overwash and redeposit sand on the backside of the barrier island, allowing the system to migrate landward as sea levels rise. In developed areas, permanent structures – private homes, businesses, roadways – obstruct the natural sand flow. In these areas, we will likely see increased coastal squeeze as barrier islands are unable to be replenished and migrate landward (Fish et al. 2005). Of the sixteen strategies offered in Fuentes et al. (2011) to mitigate the impact of sea level rise on nesting sea turtles, I

have found that only three are politically, economically, and logistically feasible in North Carolina: beach nourishment, using groins and jetties, and planning for sea level rise.

Experts caution against advocating for permanent hard-engineering structures, such as terminal groins and jetties, because they can act as barriers to females approaching the area to nest. Adult females may attempt to crawl around them, move to another area of the beach – provided another area is available – or abort nesting entirely. While beneficial in the short-term for mitigating the effects of beach loss and sea level rise, hard structures may actually hinder the ability of beaches to rejuvenate over time (Fish et al. 2008). Holden Beach, Ocean Isle Beach, Bald Head Island and Figure Eight Island, along with the USACE should not only include sea level rise into the four terminal groin project plans, but I also highly recommend that groin construction, if permitted, avoid sea turtle nesting season. Construction during nesting season may destroy nests, disturb nesting females, or harm emerging hatchlings (NMFS and FWS 2008).

Sea level rise is not a current planning priority for either Carteret or New Hanover Counties' shore protection managers. There has been mention of accounting for 1 meter of sea level rise by 2050 in Carteret County, but no official consideration. To account for the rise, the shoreline protection offices would have to account for an additional volume of sand needed for each project, and increase that amount for future maintenance projects as sea levels rose. Given local counties and municipalities are already grappling with securing funding for current projects, adding in the additional sand required (and therefore money required) to construct the same beach profile after seas have risen by 1-3 feet is simply not feasible in the eyes of coastal managers. In the 2011 BIMP, sea level rise was mentioned as a long-term threat to beach and inlet management (BIMP 2011, pg. IV-1); but it was determined that there was not enough information to officially plan for that threat. As a result, beach and inlet management projects (such as nourishment and terminal groin construction) are moving forward and being permitted without consideration for how sea level rise will impact the total lifetime cost.

Recommendations

1. Garner state-level support for sea level rise planning.

The North Carolina Sea Grant Strategic Plan for 2014-2017 calls for incorporating the prospect of rising sea levels in new coastal investment plans and policies. However, House Bill 819/Session Law 2012-202 mandates that the State cannot define rates of sea level rise for policy or planning purposes until July 1, 2016. Mentioned in the 2012 "Addendum to the North Carolina Sea Level Rise Assessment Report of 2010," several other states and agencies are prioritizing sea-level rise planning, including:

Maine, Delaware, Louisiana, California, Florida, and the USACE (Addendum 2012, pg. 5). The reorganized CRC may oppose sea-level rise planning, but such planning will be required if county and municipal governments are to develop economically and ecologically responsible policies.

Section 2(c) of HB 819 mandates the CRC Science Panel creates a follow-up “North Carolina Sea Level Rise Assessment Report” by March 31, 2015. The ruling requires the CRC Science Panel to include a comprehensive review of the best scientific literature available, hopefully minimizing bias and sparking an honest conversation about the threat of sea level rise in North Carolina. The Science Panel should include the Intergovernmental Panel on Climate Change 5th Assessment Report – the Synthesis Report is expected in 2014 – as well as North Carolina-specific peer-reviewed sea level rise projections, and associated economic and ecological analyses. I recommend the CRC adhere to this ruling and adopt a projection of sea level rise for which county and municipal governments can plan for.

2. Account for the increased need for sand in future nourishment projects.

The level of sea level rise agreed upon by the CRC should be incorporated into the nourishment permitting process. Furthermore, the DCM should require shoreline protection managers and the USACE to incorporate the increased need for sand into future nourishment projects to avoid underestimating how much sand will be needed and the total lifetime cost of each project. Both the Bogue Banks Master Beach Nourishment Plan (Moffatt & Nichol, et al. 2014) and the BIMP Draft Report (NCDENR 2009) discussed the additional volumes of sand needed to adapt to relative sea level rise change scenarios. However, it should be noted that as a result of controversy over HB 819, the calculations to incorporate additional volumes of sand were removed from the BIMP Final Report (NCDENR 2011). Originally, the BIMP Draft Report assumed that 1 foot of sea level rise would require an additional 1.3 cubic yards of sand volume to be placed throughout the entire shoreline profile – or an additional 10-20% of sand needed. A more in-depth engineering study for the Bogue Banks Master Beach Nourishment Plan calculated the additional volume of sand needed for three different design scenarios – one accounting for 0.57 feet of rise (low), one accounting for 1.01 feet of rise (intermediate), and one accounting for 2.39 feet of rise (high). The report states that “based on USACE guidance provided at the PRT meetings, the intermediate should be used for planning purposes. Therefore, the additional need to account for potential sea level change would be 1,825,000 [cubic yards], equating to a total need 46.8 to 51.6 [million cubic yards]” (Moffatt & Nichol, et al. 2014, pg. 171). With a historic average cost of \$13.25 per cubic yard of sand in Carteret County, this would equate to an additional

\$24,181,250 in total costs over the lifetime of the project. Not accounting for this additional amount of sand needed is economically irresponsible.

3. Incorporate color into the Sediment Criteria Rules.

Peterson & Bishop (2005) found that 84% of (39/46) beach nourishment biological monitoring efforts failed to statistically test associations between physical habitat and biological responses. I first recommend that the CRC maintain the Sediment Criteria Rules and impose firmer regulations during permitting so that coastal construction projects must adhere to the environmental windows (Arnold 1992). I also recommend the CRC take steps to incorporate sand color into the guidelines. Sand color can dictate sand temperature, with darker sand trapping more heat than lighter colored sand. Given that sex is determined in sea turtles during incubation, with cooler temperatures tending to yield males and warmer temperatures tending to yield females, artificially altering the sand color by placing a different color sand than what is native to a beach might further skew sex ratios towards female-dominance.

4. Create local-level tax plan to finance future nourishment projects.

Historically, 50-year nourishment projects were funded 65% from federal funding, 26.25% state funding, and 8.75% local funding (Annabelle 2010a). However, given the current economic downturn and federal cutbacks, federal funding for nourishment is minimal except in emergency situations, such as after major storms as part of the FEMA's Public Assistance Program (Annabelle 2010a). This has prompted county and municipal governments to look for new ways to secure nourishment funding. In 2000, the Carteret County Shore Protection Office began the 100% locally-funded Bogue Banks Restoration Project and in 2010 began putting together plans for a 50-year Master Nourishment Project. Initial funding for the Restoration Project came via bonds backed by the USDA. Since a county-wide bond referendum failed in 2000, Carteret County towns are taxed varying rates as a result of bond referendums passed (Annabelle 2010a). Half of the Bogue Banks projects are paid for via the Carteret County Room Occupancy and Tourism Tax (6%). Enacted in 2001 (SL 2001-381) and codified in 2013 as SL 2013-223, 3% of this tax is remitted to a fund that is to be used exclusively for beach nourishment projects (GL Rudolph, personal communication, November 6, 2013). There is an 11-member group that makes decisions concerning the fund. The Carteret County Shore Protection Manager suggested proposed a tax plan that required property owners closest to the beach to pay higher taxes than those

properties furthest from the beach. These taxes, along with a continued occupancy tax paid by visiting renters and hotel stays, would feed a fund specifically for beach nourishment.

New Hanover County has collected Room Occupancy and Tourism Tax since 1983 – the current rate is 6% on area hotel stays and short-term rentals. Sixty percent of the first 3% goes directly into a fund for beach nourishment projects while the other 40% goes towards the Tourism Development Authority and Visitors Bureau. Fifty percent of the second 3% goes toward tourism marketing while the other 50% varies uses but must be spent on activities that enhance tourism (*GS 153A-155* and *GS 160A-215*). On March 26, 2014, the New Hanover County Tourism Development Authority denied a request to use a portion of tourism-marketing funds on beach nourishment in the county (Stansell 2014). Then in April 2014, an article appeared in the *Star News Online* that suggested Carolina Beach, Wrightsville Beach, and Kure Beach town leaders may push for a new tax on prepared food and beverages to help fund future beach nourishment projects in the county (Queram 2014). For this to happen, the town leaders would have to garner unanimous support from county legislatures and, with the Tourism Development Authority declining their request to free-up some of the occupancy tax funds, such support may be challenging.

Brunswick County has collected only a 1% Room Occupancy Tax since January 1998. Brunswick County does not have an organized Shore Protection Office/Manager like Carteret and New Hanover Counties. Peterson & Bishop (2005) suggested the impacts of projects should be looked at as a whole, instead of the current project-by-project approach. I recommend the county assign this office/manager to ensure a county-wide approach to beach nourishment.

5. Continue monitoring nesting beaches for any changes post-nourishment.

The Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle identifies 34 priority actions “that must be taken to prevent the extinction or to prevent the species from declining irreversibly in the foreseeable future... [which include] monitoring trends on nesting beaches and at in-water sites; minimizing the effect of coastal armoring; maintaining the current length and quality of nesting beach; [and] acquiring and protecting additional properties on key nesting beaches” (NMFS and FWS 2008, pg. xii). Historically, sea turtle nesting conservation efforts in North Carolina have been from the ground up, with local volunteer groups coordinating nesting management with the guidelines of the FWS and the state WRC. If the proposed critical habitats become codified, then the FWS and NMFS must continue to coordinate with the WRC and these local volunteer groups. From 2011-2012, volunteers contributed 40,660 hours to monitor nesting beaches. This is equivalent to

\$626,589 in volunteer labor that is at no cost to the state. These efforts are crucial for the effective management of the loggerhead sea turtle.

Data Gaps and Suggestions for Future Studies

One of the greatest challenges for sea turtle management in North Carolina is a lack of data. Unlike Florida, which has been monitoring loggerhead nesting for years, many North Carolina beaches have only recently begun citizen-led monitoring efforts, some as recently as the late 2000s. Data gaps for loggerhead nesting across the state makes it challenging to quantitatively assess the impacts of beach nourishment, or other, projects on nesting success. The mechanisms by which a female sea turtle chooses an area to dig and lay her nest remain a mystery. Until this critical information gap is resolved, it will be impossible to determine if a recently nourished beach deters nest site selection.

In Florida, a collaborative effort to create a turtle friendly beach design is underway. Led by R.G. Ernest and R.E. Martin at Ecological Associates, Inc., this effort would shape the nourished beach profile to something more alike a typical beach profile (see Figure 6). A pilot project is currently underway in Martin County, Florida, with construction ending winter 2013. The upcoming 2014 nesting season will be the first documentation of how this adjusted profile influences nest site selection and nesting success. Depending on the outcome of the project, the USACE may consider constructing the initial profile more like that of the “profile design” instead of leaving it to equilibrate itself. It will be worthwhile to follow-up on the results of the “Turtle Friendly Beach Design” in Florida to see if the new beach profile design is increasing nesting success relative to the typical profile design standards.

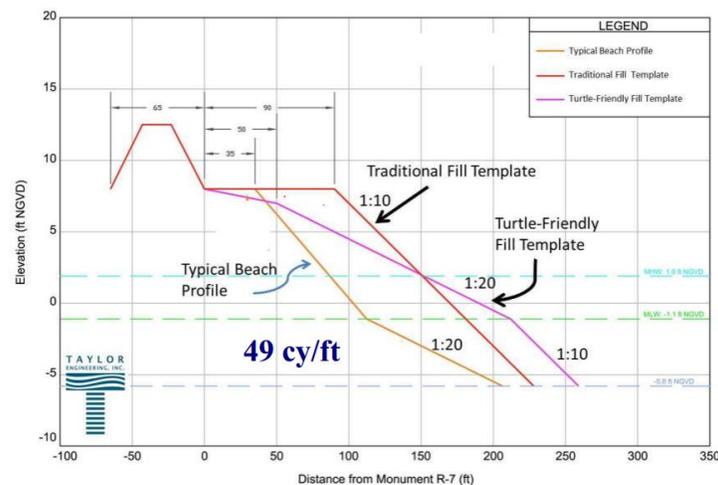


Figure 6. Taken from Ernest et al. (2012) showing the profile differences between a typical beach profile, a traditional profile after beach nourishment, and the proposed turtle-friendly construction profile.

Other future studies should assess the feasibility of the other thirteen adaptation strategies outlined by Fuentes et al. (2012), listed in Appendix A. Given the current political and economic climate in North Carolina, only continued beach nourishment, consideration of terminal groin structures, and incorporating sea rise into future planning and policies, are currently feasible. Once the CRC Science Panel completes the updated Sea Level Rise Assessment Report in 2015, and once the current legislative session is complete, perhaps other strategies will become viable.

Conclusions

With an increasing rate of sea level rise and enhanced storm activity, many state and local governments are turning toward engineered solutions to combat erosion (Barth & Titus 1984). Current management strategies in North Carolina fail to take into account the effect of sea-level rise on sea turtle populations. Sea turtle survival will depend, at least in part, on the effectiveness of future conservation strategies and management plans that take projected sea-level rise into account (Fuentes et al. 2012). It is critical that North Carolina's barrier island beaches are maintained and protected in a sustainable way to ensure the survival of loggerhead sea turtles. Investing in policies and legislation designed to protect beaches (and turtles) will not only yield positive ecological advantages, but will also benefit the tourism industry, coastal landowners, and the general public. Strong collaboration between coastal managers, conservation teams, and researchers is necessary.

As proven by the controversial HB 819 sea level rise legislation in 2012, there is much political hesitation in the current North Carolina legislature about planning for future sea level rise scenarios. Projects today are already costly and incur a significant strain on local and state governments. This hesitation is enhanced by the fact that the election cycle is every 2-4 years. Legislators tend to not be focused on what *may* happen 20, 50, 100 years from now – they are concentrated on what is best for their constituents right *now*. However, it is important that governments take steps today to account for sea level rise, especially when managing protected species. There will be impacts to loggerhead sea turtles with each beach protection project, but the ultimate goal of this research was to suggest ways in which these impacts may be minimized over the long term.

Due to the regulatory restrictions imposed by HB 819, plans *cannot* take sea-level rise into account at this time, but again, I recommend the state make sea-level rise planning a priority after the release of the updated "North Carolina Sea-Level Rise Assessment Report" in 2015 and that the state

require all new 50-year nourishment plans and Beach and Inlet Management Plans to factor in sea-level rise. All beach protection management agencies must also continue to work with the NMFS, FWS, WRC, and sea turtle volunteer groups to ensure sea turtle safeguards during construction. Solutions to protected species management in the face of sea-level rise will be politically and publically challenging and involve a wide range of stakeholders, but cooperative planning is necessary to ensure a vibrant economy and ecologically sustainable North Carolina coastline.

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Appendix A

Fuentes et al. (2012) strategies to mitigate the impacts of sea level rise on the terrestrial reproductive phase of sea turtles

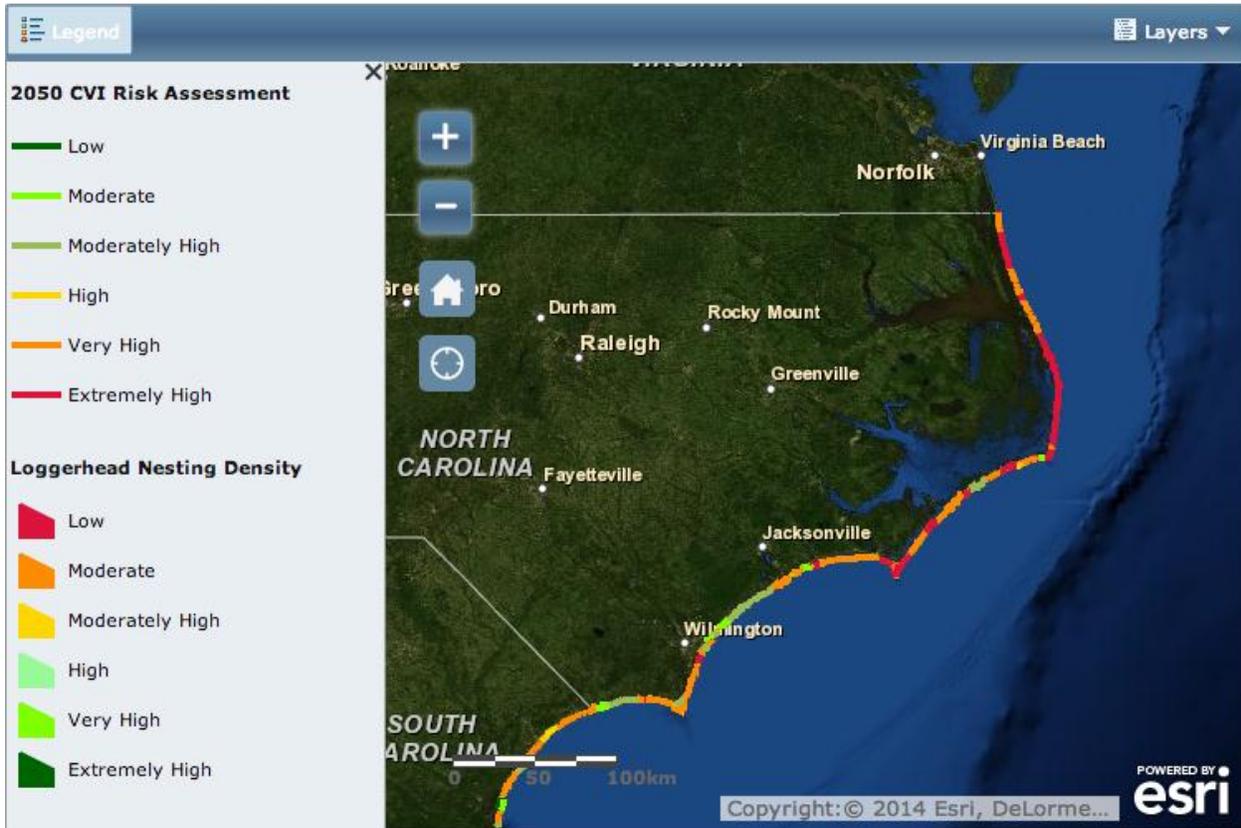
Recommended Strategies	
1	Prevent removal of beach vegetation
2	Re-vegetation or planting native vegetation
3	Identify and legally protect areas that will have suitable nesting environment as climate changes
4	Establish rolling easements
5	Incorporate climate change into land-use planning
6	Establish or enforce existing setback regulations
7	Ban and remove permanent shoreline-hardening structures
8	Plan urban growth to redirect development away from nesting areas
Potential Strategies	
9	Beach replenishment
10	Install offshore breakwaters
11	Use hard engineering structures (e.g. groins)
12	Move nests to areas with suitable incubating environment in the beach (in situ)
13	Move nests to hatcheries
14	Move nests to incubators
15	Move nests to other existing nesting beaches that have more suitable incubating environment
16	Create artificial beaches and move nests to those areas

Adapted from Table 1 in Fuentes et al. 2012 (pg. 55). Recommended strategies are considered best choice while potential strategies should be last resort. For a more detailed discussion of methods, costs, and reasoning, see Fuentes, M.M.P.B., Fish, M.R., and Maynard, J. (2012). Management strategies to mitigate the impacts of climate change on sea turtle's terrestrial reproductive phase. *Mitigation and Adaptation Strategies for Global Change*, 17(1), 51-63.

Appendix B

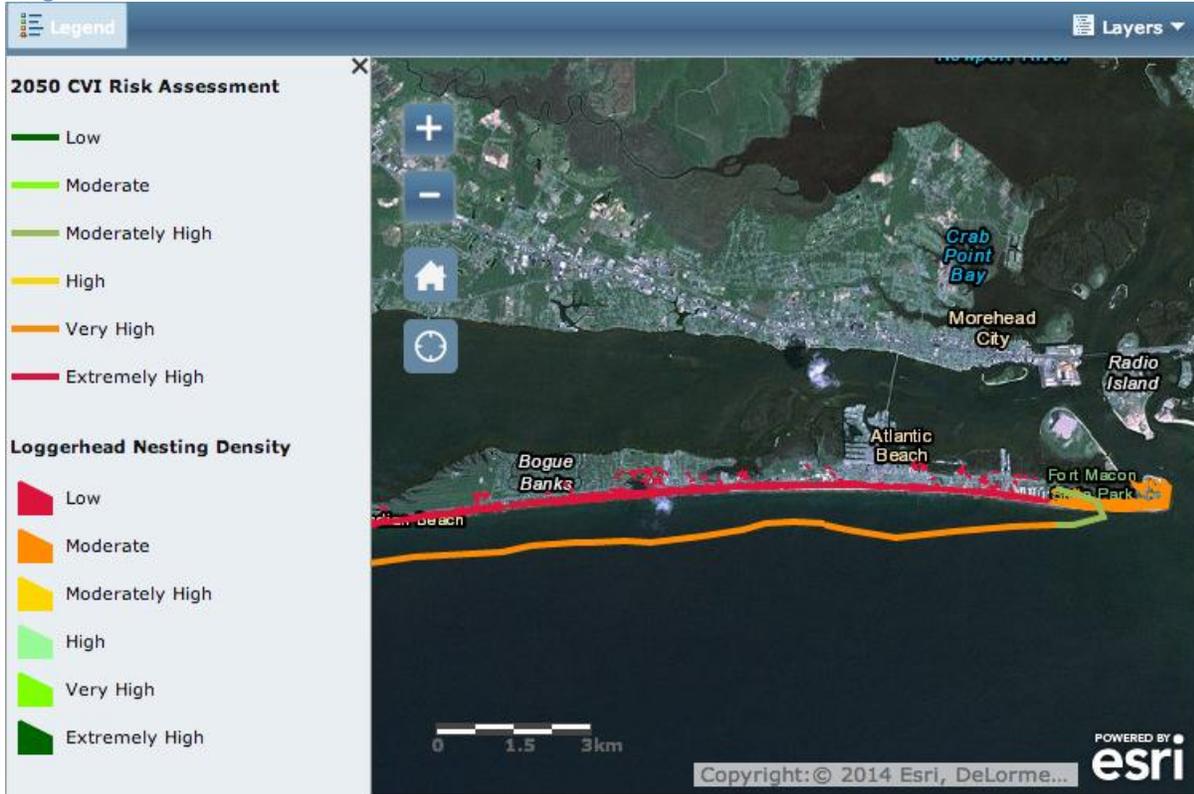
The following maps were developed by Von Holle et al. (2014, in progress) with funding provided by South Atlantic Landscape Conservation Cooperative. Maps were generated on the unpublished Von Holle Lab page and are to be used solely for the purposes of this report. For this study, I was interested in areas with “Moderately High” to “Very High”¹ loggerhead nest density and a “Very High” or “Extremely High” Coastal Vulnerability Index (CVI). The USGS CVI ranking indicates an area’s vulnerability to sea level rise.

All North Carolina

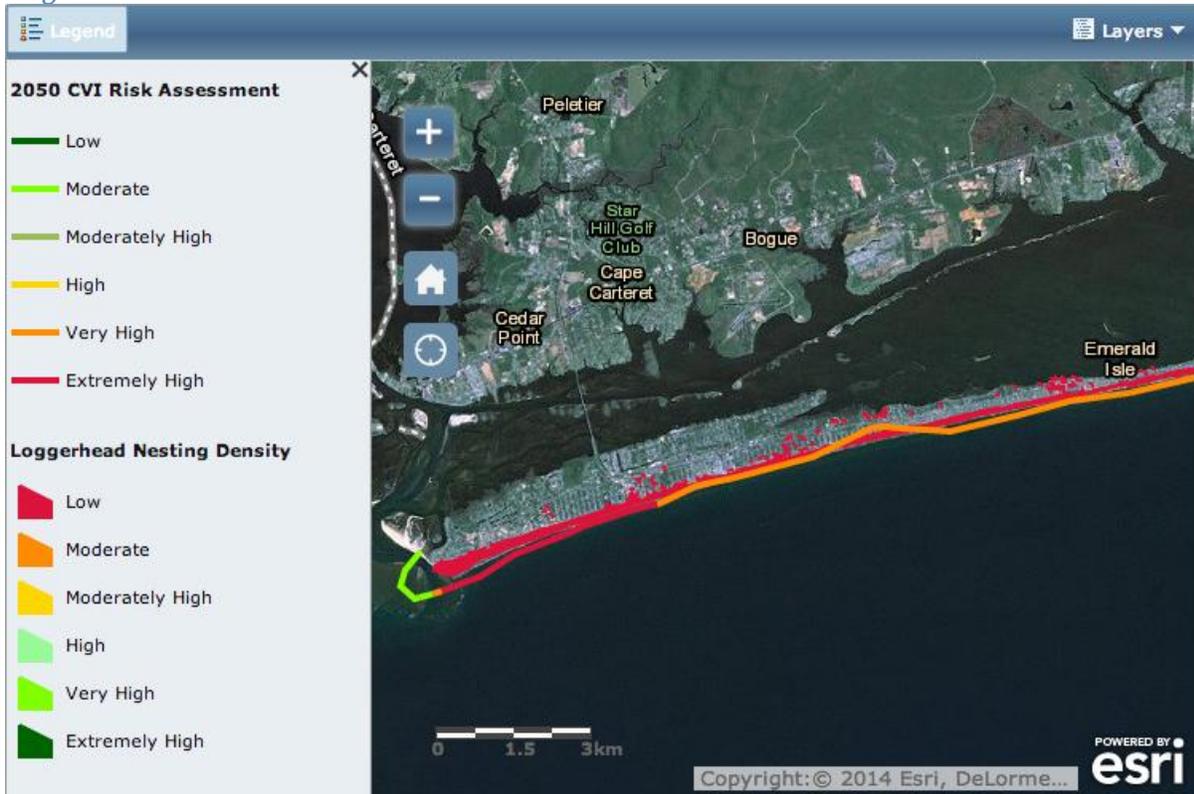


¹ “Extremely High” loggerhead nest density only occurs in Florida and is therefore not relevant to this study.

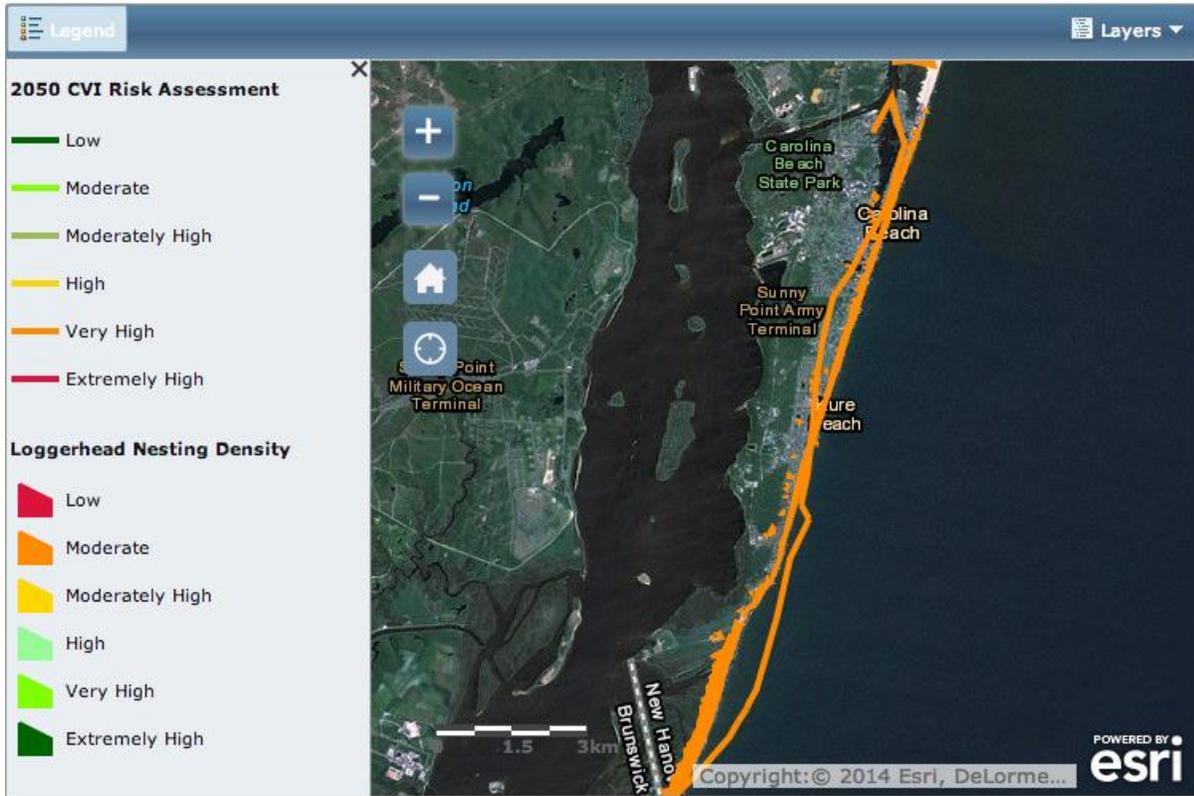
Bogue Banks - North



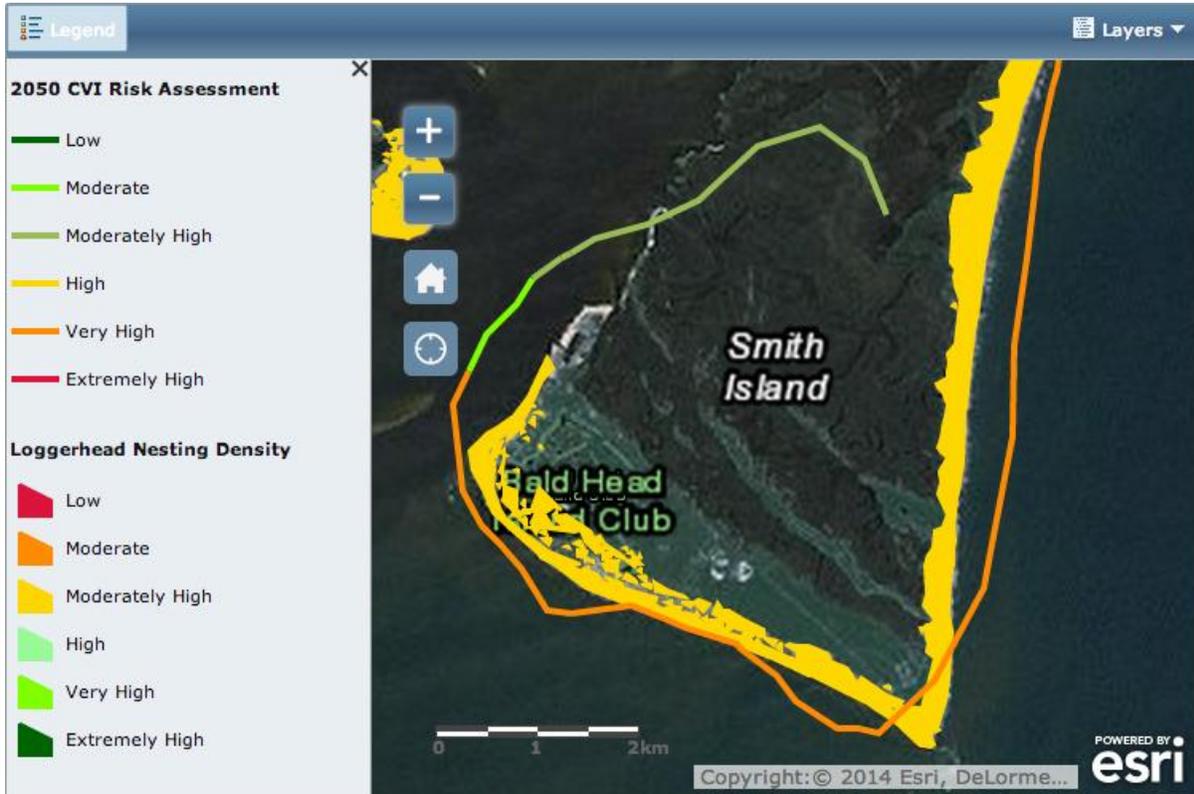
Bogue Banks - South



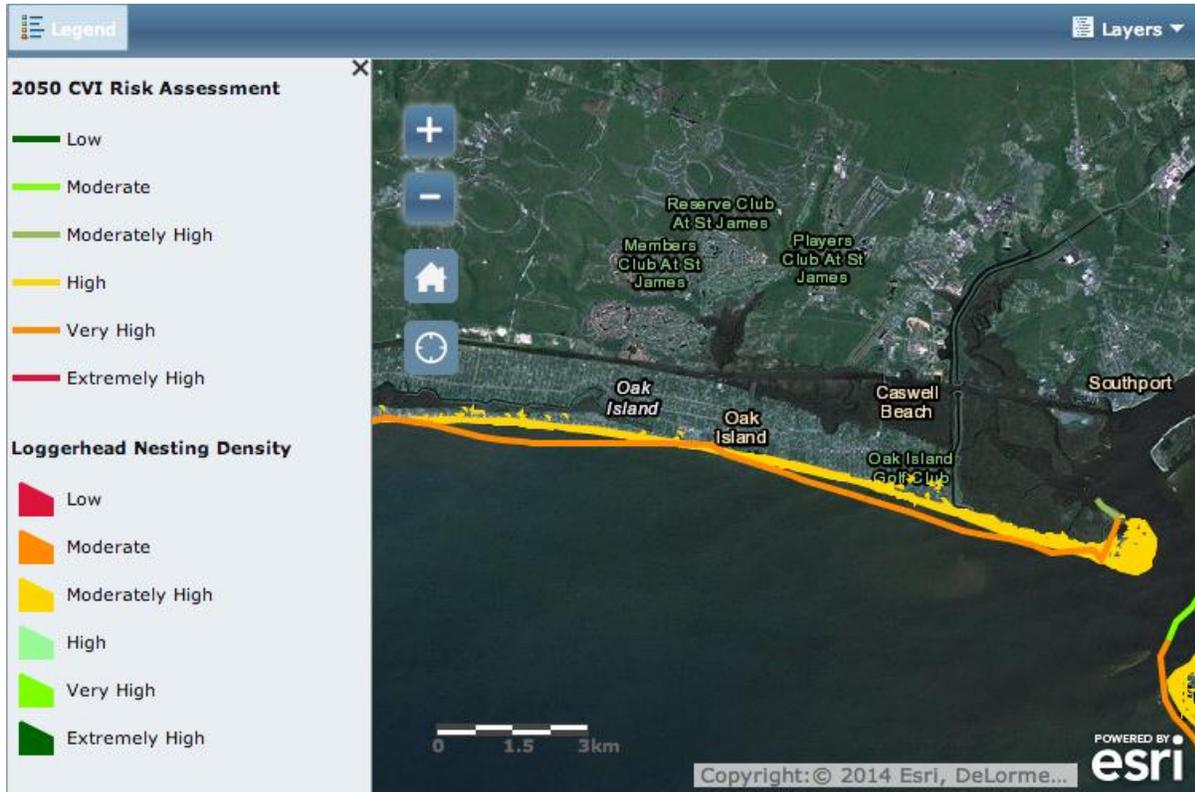
Pleasure Island



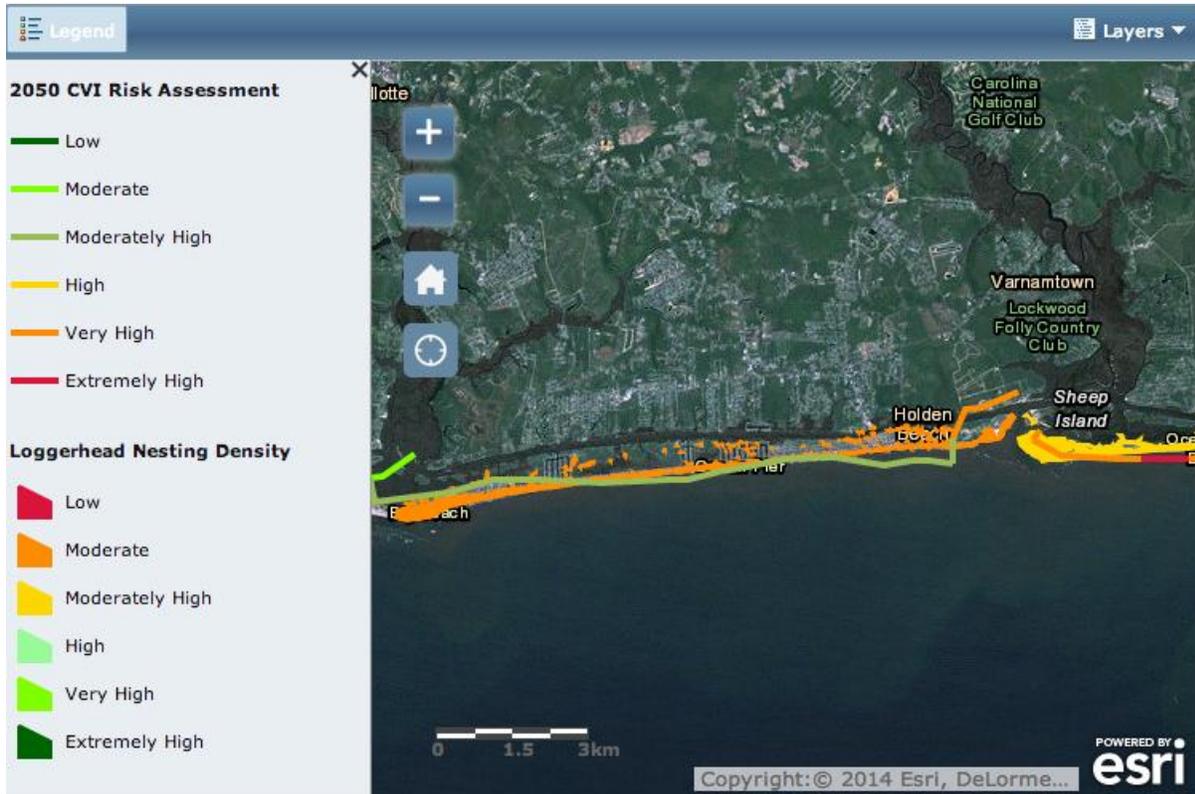
Bald Head Island



Oak Island



Holden Beach

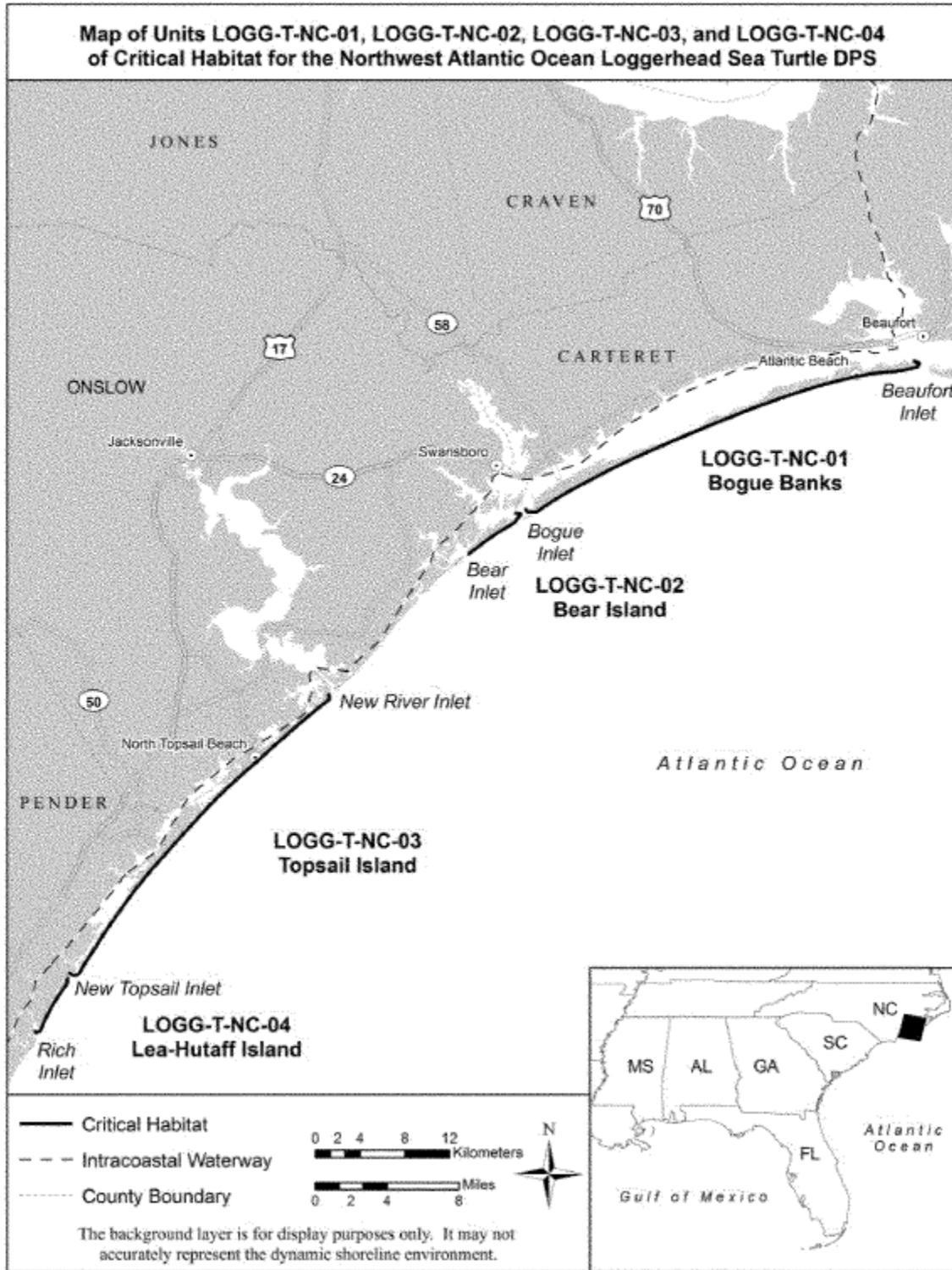


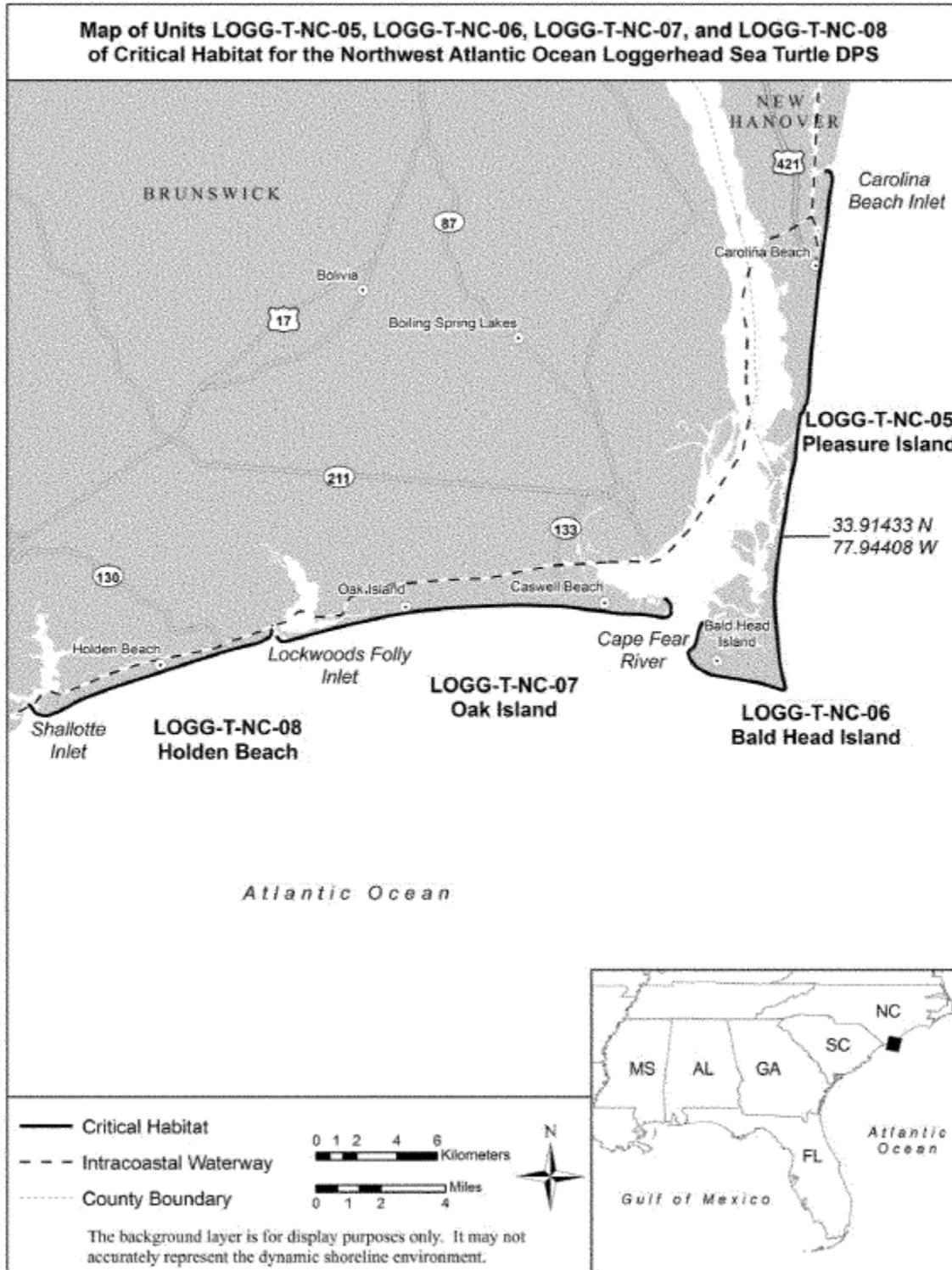
Appendix C

Loggerhead nesting density by beach

Beach	Length (km)	1998-2013 Total Nests	Average Nests per Year	Nests per km
Virginia border to Nags Head	28.97	159	9.94	0.34
Cape Hatteras National Seashore	62.76	1,706	106.63	1.70
Pea Island Wildlife Refuge	106.22	207	12.94	0.12
Cape Lookout National Seashore	90.12	2,381	148.81	1.65
Fort Macon State Park	4.83	48	3.00	0.62
Bogue Banks	28.97	440	27.50	0.95
Hammocks Beach State Park	6.44	277	17.31	2.69
Onslow Beach	11.27	710	44.38	3.94
Topsail Island	35.41	1,484	92.75	2.62
Lea Island	3.22	65	5.91	1.84
Huttag Island	4.83	6	2.00	0.41
Figure Eight Island	6.44	214	13.38	2.08
Wrightsville Beach	8.05	74	4.63	0.57
Masonboro Island	12.87	253	19.46	1.51
Carolina Beach	6.44	121	7.56	1.17
Kure Beach	4.83	149	9.31	1.93
Fort Fisher State Recreation Area	4.83	368	23.00	4.76
Bald Head Island	14.48	1,175	73.44	5.07
Caswell Beach	4.83	841	52.56	10.89
Oak Island	16.09	1,060	66.25	4.12
Holden Beach	11.27	608	38.00	3.37
Ocean Isle	8.05	335	20.94	2.60
Sunset Beach/Bird island	4.83	188	11.75	2.43

Source: MH Godfrey, WRC, 2013. Beaches highlighted in blue are within my study area.





Appendix E

Regressions of number of nests per year for all North Carolina beaches

