XI. Region 4

Region 4 is composed of three subregions (4a, 4b, and 4c) that extend from Cape Hatteras at Buxton to the Virginia/North Carolina border. Region 4 covers Dare County and Currituck County.

Region 4a (Figure XI-1), encompasses the eastern facing shores of Dare County from Cape Hatteras at Buxton to just north of the town of Rodanthe. The communities of Buxton, Avon, Salvo, and Rodanthe are included in this region. Region 4a has no inlets.

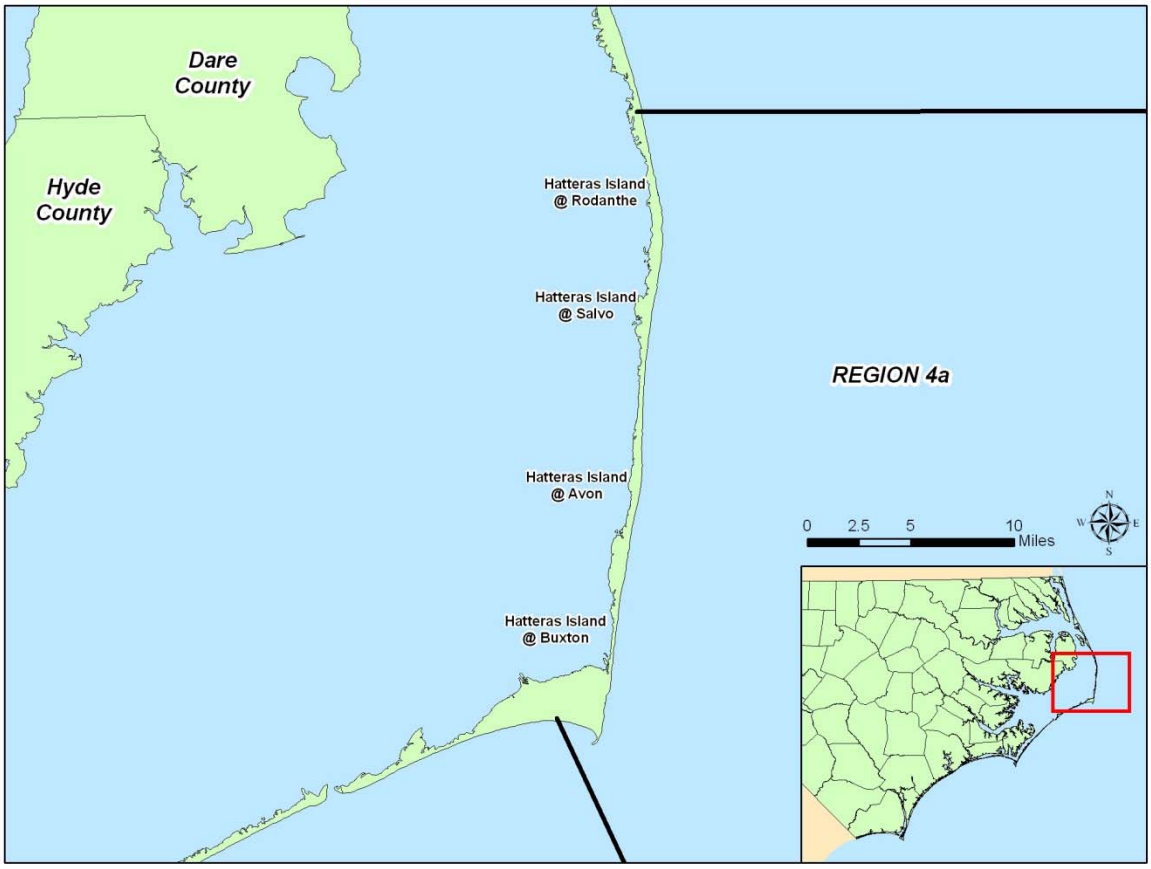

Figure XI-1 Region 4a Boundaries

See Table XI-1 for approximate shoreline development lengths. National Seashore lands are designated "Not to be Developed." Unincorporated areas of the county constitute the developed areas.

Table XI-1. Region 4a Shoreline Development Lengths

Shoreline Type	Shoreline Length (mi)
Not Developed	0
Developed	11
Not to be Developed	24
Total	35

The areas not included in the four communities of Hatteras Island in this subregion are federally-owned National Seashore. See Table XI-2 for details.

Table XI-2. Region 4a Shoreline Ownership Lengths

Shore Ownership	Shoreline Length (mi)
Municipal	11
State	0
Federal	24
Private	0
Total	35

No length of shoreline in this subregion is currently actively managed (Table XI-3). However, the DOT does occasionally undertake sand pushing operations at NC12 hotspots.

Table XI-3. Region 4a Shoreline Management Lengths

Management	Shoreline Length (mi)
Managed	0
Not Managed	35
Total	35

The second subregion, Region 4b, extends from Pea Island to the Dare County/Currituck County border. Pea Island, Bodie Island, Nags Head, Kill Devil Hills, Kitty Hawk, Southern Shores, Duck and Sanderling all fall within Region 4b. Oregon Inlet is the only inlet in this region and the only inlet in all of region 4. Figure XI-2 shows the boundaries of Region 4b.

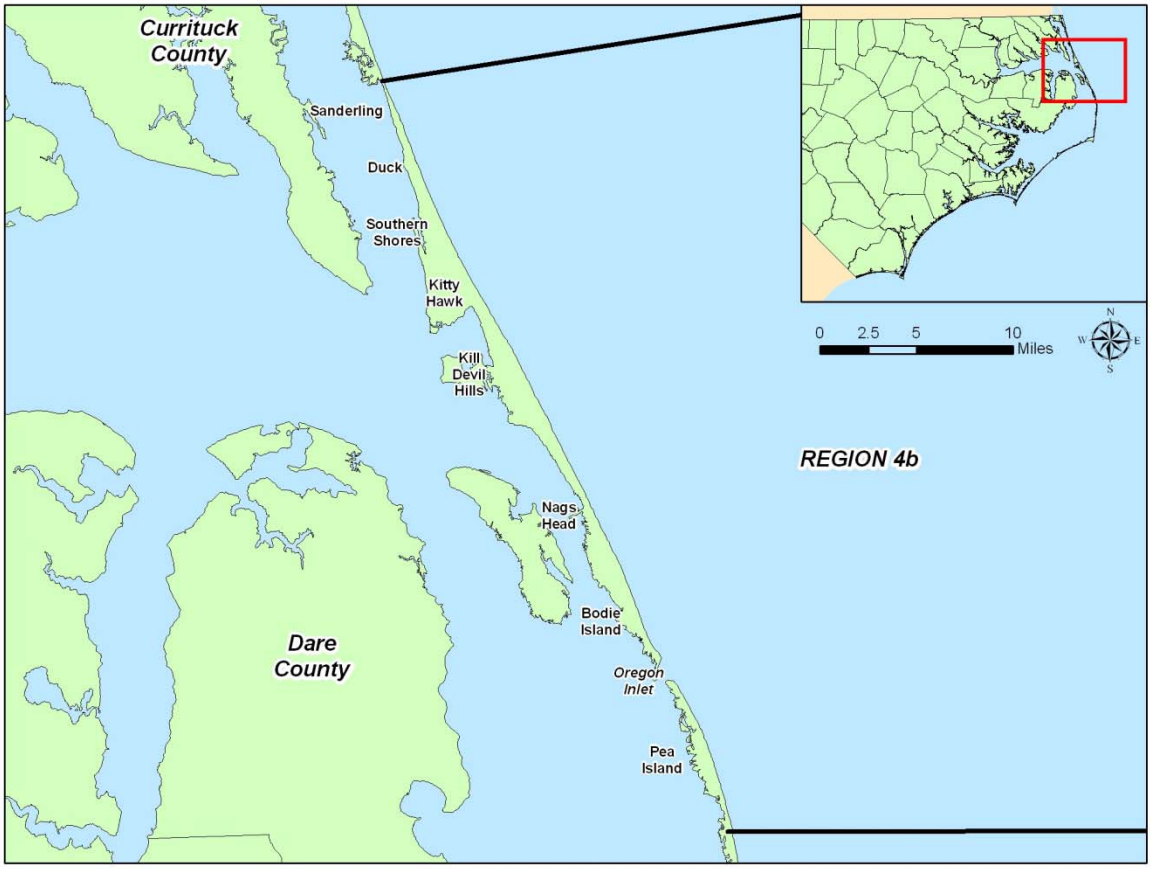

Figure XI-2. Region 4b Boundaries

The developed areas in this subregion are located within municipalities. The remainder is designated "Not to be Developed" and is located on federal lands. See Tables XI-4 for details.

Table XI-4 Region 4b Shoreline Development Lengths

Shoreline Type	Shoreline Length (mi)
Not Developed	0
Developed	28
Not to be Developed	15
Total	43

Municipalities, National Seashore and Wildlife Refuges make up the shoreline ownership in this subregion. See Table XI-5 for approximate shoreline ownership lengths.

Table XI-5. Region 4b Shoreline Ownership Lengths

Shore Ownership	Shoreline Length (mi)
Municipal	28
State	0
Federal	15
Private	0
Total	43

The actively managed area in this subregion is located on the northern six miles of Pea Island. The remainder of the subregion is not actively managed (Table XI-6).

Table XI-6. Region 4b Shoreline Management Lengths

Management	Shoreline Length (mi)
Managed	6
Not Managed	37
Total	43

The third subregion, Region 4c, extends from the Dare County/Currituck County border to the North Carolina/Virginia border. Region 4c includes the area known as Peter's Quarter, Corolla, the Currituck National Wildlife Refuge, and a stretch of land leading north to the Virginia Border. There are no inlets in this region. Figure XI-3 shows the boundaries of Region 4c. Note that the northernmost area of Region 4c is referred to as "NC to VA" or "Refuge to VA" throughout this report. The area extends from the Wildlife Refuge to the North Carolina/Virginia border, per Division of Coastal Management (DCM) naming conventions.

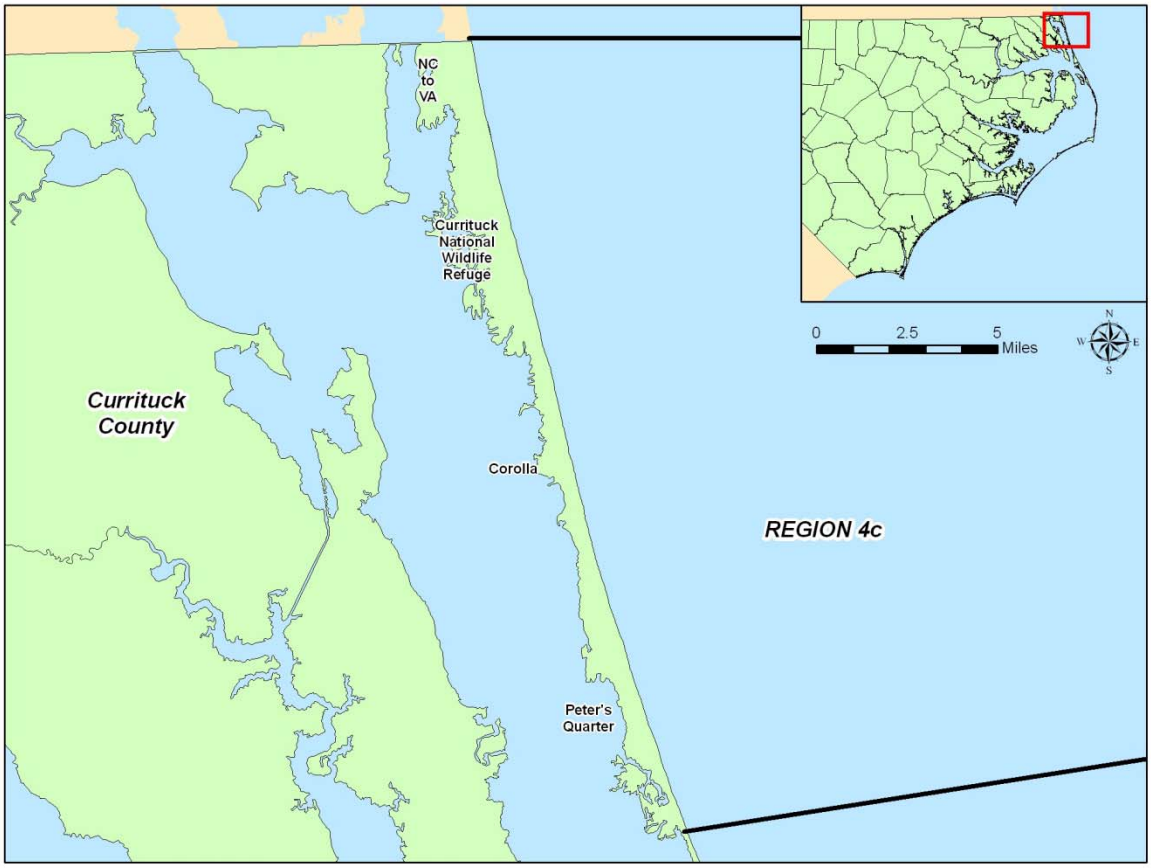

Figure XI-3. Region 4c Boundaries

The northernmost shoreline in this subregion is not developed. State and federal lands are designated "Not to be Developed." The remainder is developed municipalities. See Table XI-7 for details.

Table XI-7. Region 4c Shoreline Development Lengths

Shoreline Type	Shoreline Length (mi)
Not Developed	1
Developed	18
Not to be Developed	4
Total	23

The federal and state-owned lands include the Currituck National Wildlife Refuge and the Currituck Banks component of the N.C. National Estuarine Research Reserve. Municipalities make up the remainder of the shoreline in this subregion. See Tables XI-8 for details.

Table XI-8. Region 4c Shoreline Ownership Lengths

Shore Ownership	Shoreline Length (mi)
Municipal	19
State	1
Federal	3
Private	0
Total	23

There is no shoreline in this subregion that is currently actively managed. See Table XI-9 for details.

Table XI-9. Region 4c Shoreline Management Lengths

Management	Shoreline Length (mi)
Managed	0
Not Managed	23
Total	23

A. Current Available Pertinent Datasets

1. Waves and Water Levels

Beaches, as the transition zone between land and water, are susceptible to changes and reshaping by waves, winds, and currents. Waves play a major role in the shaping and evolution of beaches and inlets. Moving water suspends and transports sediment while the severity, frequency, and direction of incoming waves influence beach behavior and geometry. The Region 4 shoreline is exposed to waves from the southeast, east and northeast with Region 4b being more susceptible to waves from the east, and Region 4c vulnerable to northeast waves. Waves can have short-term, seasonal, and long-term impacts on both the cross-shore and along-shore beach shape. Drastic changes in beach width and elevation can occur during a single hurricane, but it is the more frequent storms and wave events that generally drive the overall beach configuration. Winter storms and their associated higher wave activities typically move sand offshore and gentler summer waves move the sand from the offshore back onto the beach. The typical angle of wave approach transports sand along the shoreline and inlets interrupt sand movement forming deltas due to the currents generated in the inlets by the rising and falling tides. Wave data along the North Carolina coast is available from long-term wave hindcast modeling and from measurements at wave buoys operating at various locations offshore.

Wave hindcasts are numerical models that use historical wind and meteorological data to calculate or hindcast what the waves would have been at a particular location. The United States Army Corps of Engineers Wave Information Study is an extensive hindcast model that provides wave information (height, period, and direction) for the 20-year period of 1980-99 at more than 300 stations offshore of the North Carolina coast with depths varying from 50 to 650 feet. This data is publicly available and can be downloaded from the U.S. Army Corps of Engineers' (USACE) website at

http://www.frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html.Representative data from WIS Stations in Region 4 can be seen in Figures XI-4 to XI-6. Figures XI-7 to XI-9 show the locations of WIS stations (locations where hindcast wave data is available) for all three subregions of Region 4.

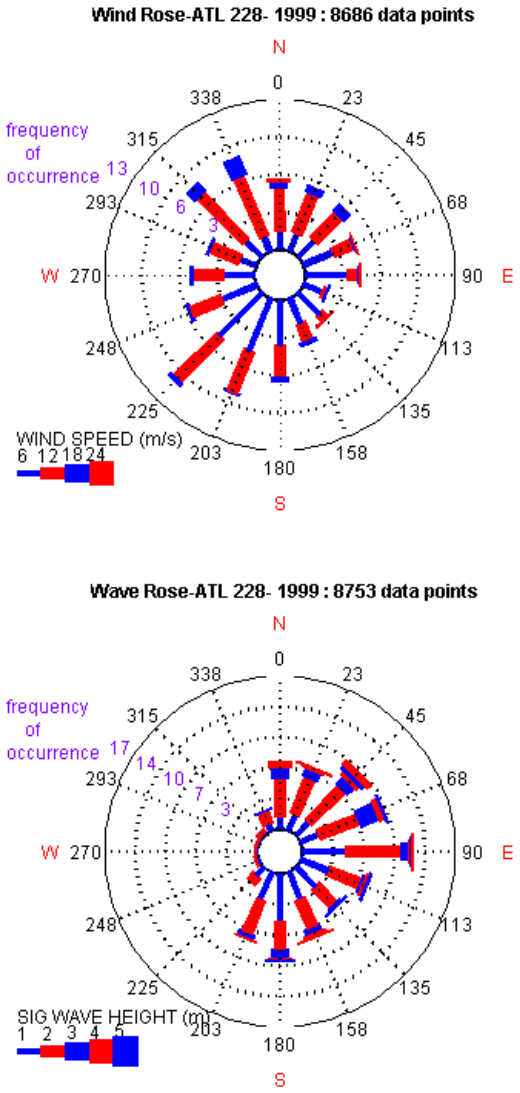

Figure XI-4. Wind and Wave Roses from Representative WIS Station 228 (Region 4a)

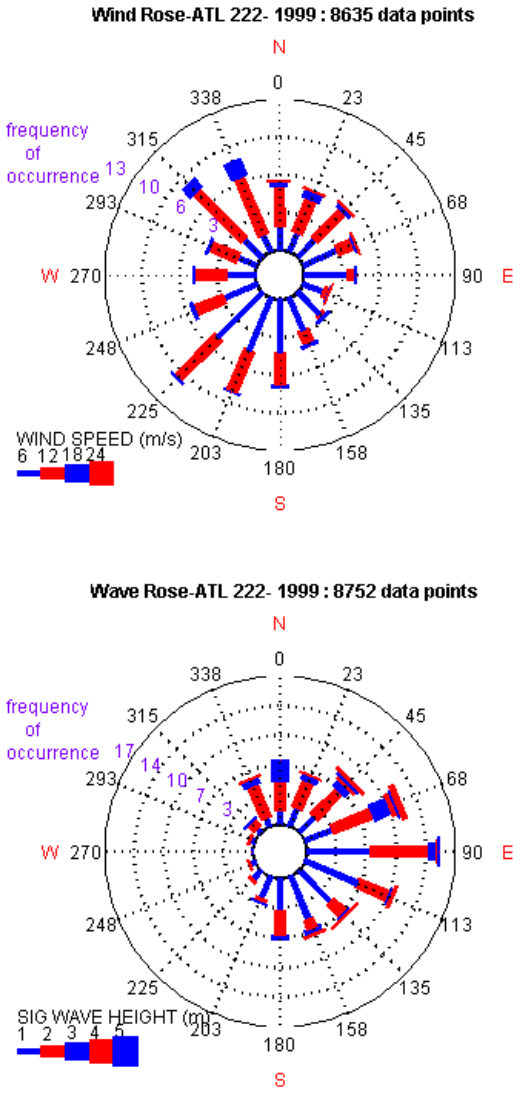

Figure XI-5. Wind and Wave Roses from Representative WIS Station 222 (Region 4b)

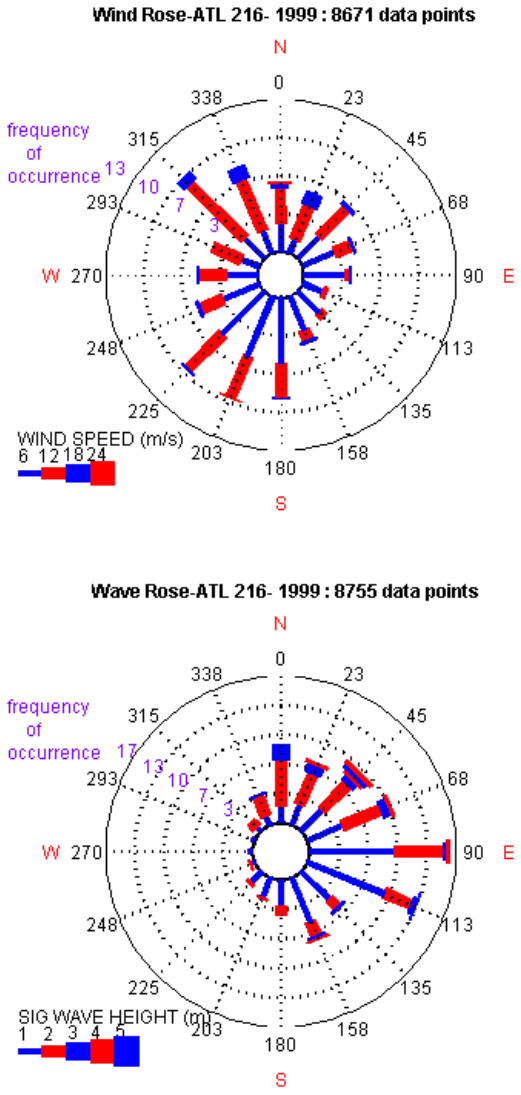

Figure XI-6. Wind and Wave Roses from Representative WIS Station 216 (Region 4c)

Note the similarities in wind direction and intensity for the three subregions. Although also similar, the wave directions and intensities vary more throughout the region. Region 4a faces in a more easterly direction and therefore receives more wave action from the south, but the wave action is still predominantly from the east. Regions 4b and 4c are oriented in much the same way and therefore their wave directions and intensities are also similar.

Wave measurements can be obtained from wave buoys off the North Carolina coast and are available from the National Data Buoy Center website at http://www.ndbc.noaa.gov/. The wave buoys also collect climatological data. Both real time and historical data can be downloaded. Figures XI-7 to XI-9 show the locations of NDBC wave buoys for all three subregions of Region 4. Region 4 also contains an Acoustic Doppler Current Profiler

(ADCP) gauge operated by the USACE Field Research Facility (FRF) in Duck, which measures wave and current data. The gauge is located offshore of Kitty Hawk, just south of the FRF facility. The abundance of data collected by the FRF in Region 4b (also applicable to Region 4a and 4c) is a large advantage for this region.

In addition to wave activity, beaches and inlets are impacted by both temporal and spatial variations in the water level. Water level variations can be regular, such as the tides, or periodic, such as storm surge. Water level changes can also occur over long periods of time due to sea level rise (climate change or relative change due to land subsidence).

Along the North Carolina coast, tides are typically semidiurnal, with two high tides and two low tides each day of similar heights. Tides are currently actively measured at six locations along the North Carolina coast by the National Oceanic and Atmospheric Administration (NOAA) and the USACE. There are two NOAA tide stations located in Region 4b, one at Oregon Inlet Marina and the other at Duck. Table XI-10 displays the tidal datums, in feet, with respect to Mean Lower Low Water (MLLW) for the two NOAA tide stations present in Region 4. The NOAA tide stations data can be found at the NOAA Tides and Currents website (http://tidesandcurrents.noaa.gov/). Figures XI-7 to XI-9 show the locations of NOAA tide stations for Region 4.

Table XI-10. Tidal Datums (ft) for Region 4 Stations

	Oregon Inlet Marina	Duck, NC
Datum	Sta 8652587	Sta 8651370
Mean Higher High Water (MHHW)	1.17	3.69
Mean High Water (MHW)	1.02	3.37
Mean Tide Level (MTL)	0.57	1.75
Mean Sea Level (MSL)	0.58	1.77
Mean Low Water (MLW)	0.13	0.14
Mean Lower Low Water (MLLW)	0	0
North American Vertical Datum (NAVD)	0.66	2.19
National Geodetic Vertical Datum (NGVD)	-0.34	1.23
Maximum Tide Level	5.66	6.92
Date Maximum Tide Level Recorded	9/16/1999	8/30/1999

Shorter term water level fluctuations due to passing storms, both extratropical (northeasters) and tropical (tropical storms and hurricanes), can elevate water levels along the coast, resulting in flooding and pushing storm surge further up the beach face, thereby reshaping it. Storm-driven water levels along the coast are available for events with a one percent annual chance of occurrence (100 year return period) from the Flood Insurance Rate Maps (FIRM) and Flood Insurance Studies (FIS) developed by the Federal Emergency Management Agency (FEMA). North Carolina is currently in the process of updating these along coastal regions, including extensive storm surge modeling. Information can be found at http://www.ncfloodmaps.com/.

Figure XI-7. Wave and Water Level Stations for Region 4a

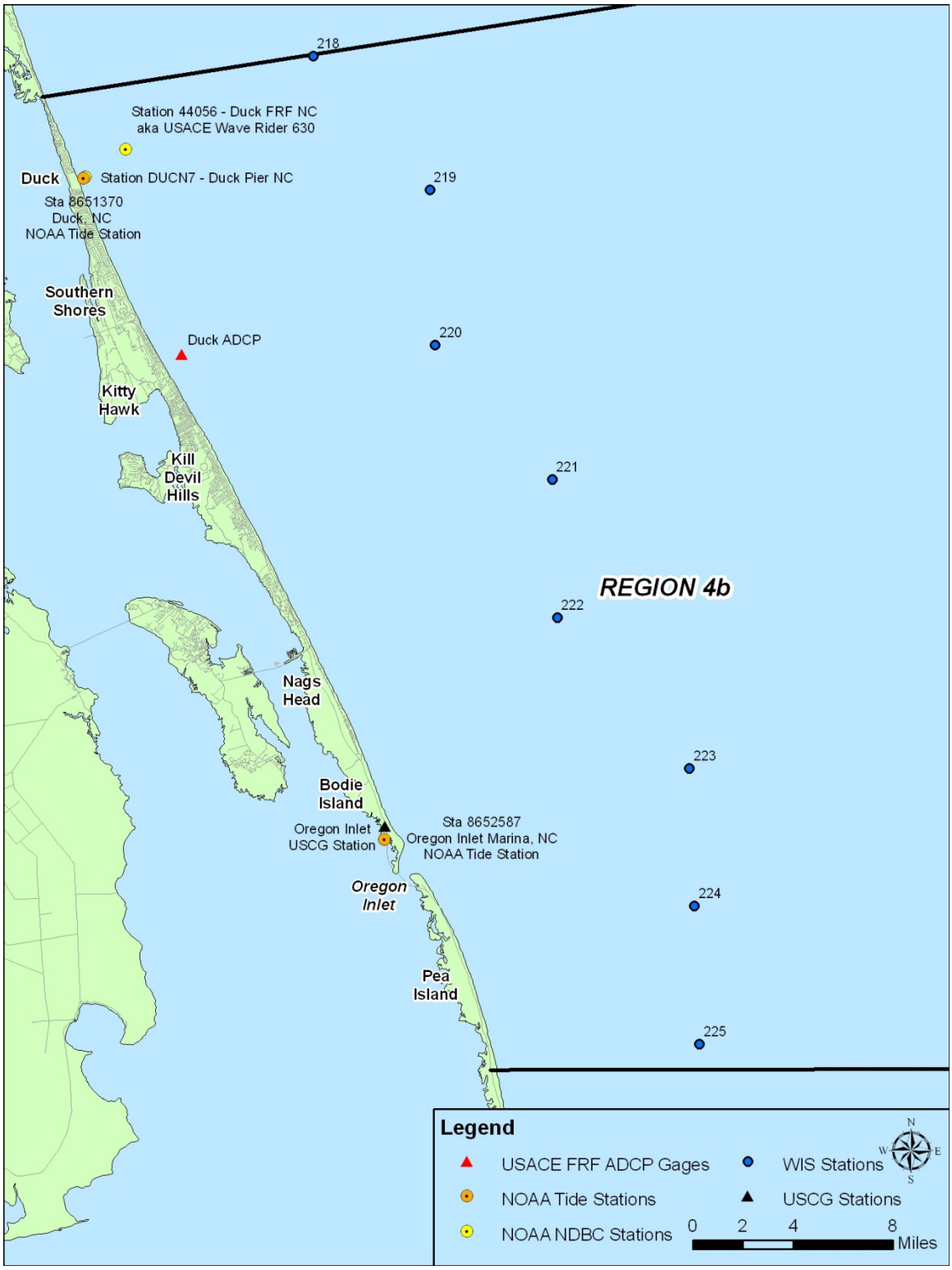

Figure XI-8 Wave and Water Level Stations for Region 4b

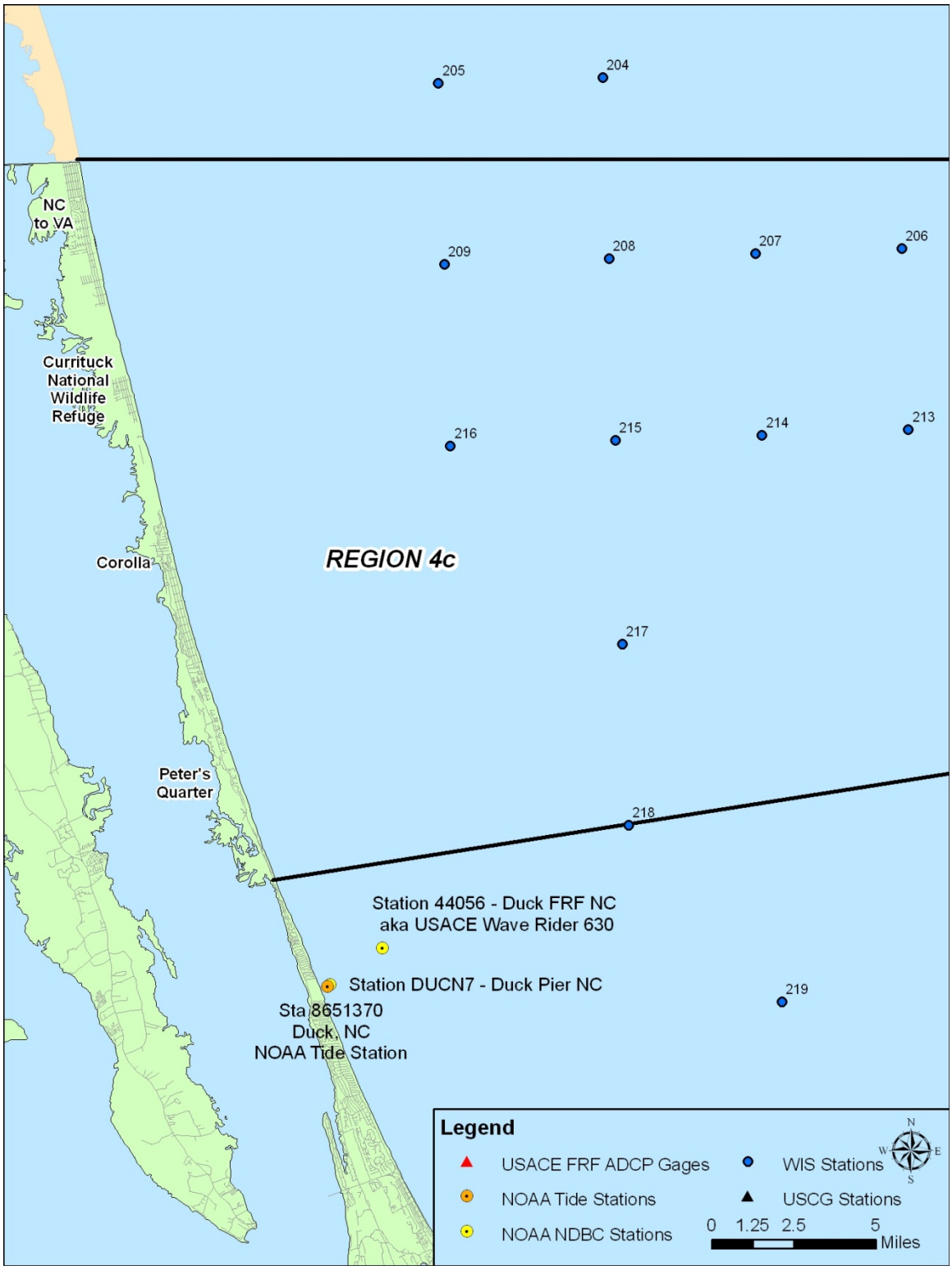

Figure XI-9. Wave and Water Level Stations for Region 4c

Due either to land subsidence, global climate changes or other factors, the relative sea level is rising along the North Carolina coast. The long term tidal water level recording stations estimate the rate of this rise as approximately 1 to 1.5 feet over the last century along the N.C. coast. For the long-term NOAA tidal measurement station at Beaufort, the mean sea level rise trend is 3.71 mm/year (1.22 feet/century) with a standard error of 0.64 mm/year (0.21 feet/century) based on monthly mean sea level data from 1973 to 1999. Figure X-10 shows the sea level rise at a tide station at Beaufort, N.C. This is the only tide station along the North Carolina coast with an uninterrupted, long-duration measurement record for which this data has been developed.

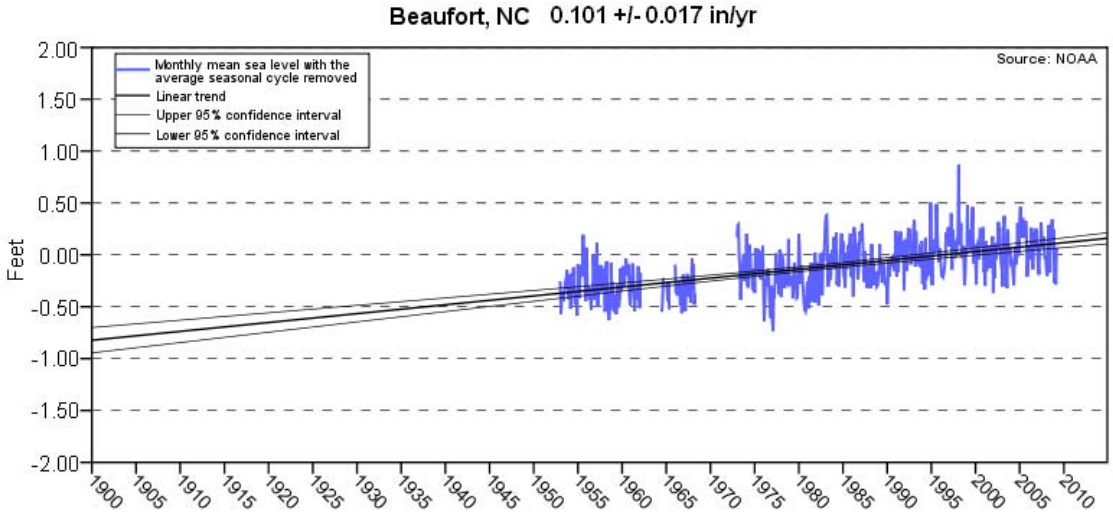

Figure XI-10. Sea Level Rise at Beaufort, NC

Planning for long-term sea level rise is difficult since consensus on how much and how quickly it will rise is difficult to achieve. There are currently many researchers, government agencies and international organizations studying the topic with conflicting predictions and disputes over the causes of sea level rise. Short-term sea level rise from 1980 to 2000 at Duck, N.C. (Dare County), based on tide level readings, is estimated to be 1.5 feet/century (Riggs, 2008). Other studies show estimates of sea level rise for the Outer Banks of 10.5 inches/century (Pietrafesa *et al.*, 2005). Note that all of these estimates are based on extrapolation of measurements less than 100. Nonetheless, the impact of rising sea levels, for which there is wide agreement, most be considered in long-term planning. It is possible to continue with strategies that are acceptable under current and shorter term historic changes, such as those predicted by the Beaufort gauge data, and then adapt as needed if conditions change in the coming years.

2. Tropical Storms

Tropical storms, especially hurricanes, can be a major episodic force in reshaping beaches and inlets (including breaching new ones through the barrier islands). NOAA maintains a GIS database of the storm tracks for Atlantic hurricanes including approximate storm location, date, wind speed, pressure, and category recorded for storms since 1851. GIS shapefiles can be downloaded at NOAA's website. Region 4 has mainly been impacted by tropical storms but has been affected by Category 1, Category 2, and Category 3 hurricanes in the past. Due to the location of this region, it is also susceptible to northeasters. Maps displaying the recorded Atlantic hurricane tracks in Region 4 since 1851 are presented in Figures XI-12 to XI14**.** Hurricane Gloria (1985) had a significant impact on Region 4a while Hurricane Bonnie (1998) impacted Region 4b. Another significant storm to impact the area was Hurricane Donna (1960), which affected Region 4c. One of the most significant storms to impact the region was not a hurricane, but rather a northeaster in March 1962, referred to as the Ash Wednesday Storm. The storm remained stationary over the North Carolina – Virginia border area for approximately three days. The storm dropped significant amounts of rain at a time of unusually high tides, causing record flooding along the Outer Banks. The NOAA National Hurricane Center Risk Analysis Program has developed estimates for return periods of hurricanes of various intensities along the U.S. coast. Figure XI-11 presents this data for the N.C. coast. The numbers indicate the expected return period (in years) on average that a hurricane can be expected within 75 nautical miles (86 statute miles) of the location. Region 4 generally experiences an average to slightly less number of hurricanes for the North Carolina coast with more frequent hurricane activity being farther south toward Cape Hatteras. For example, north of Cape Hatteras only expects a Category 1 hurricane to hit once every 15 years, while beaches further south can expect a Category 1 hurricane every 5 to 10 years (see upper left graphic of Figure XI-11). However, Region 4 is very susceptible to extratropical storms and northeasters, which are especially problematic for beach erosion given their extended durations.

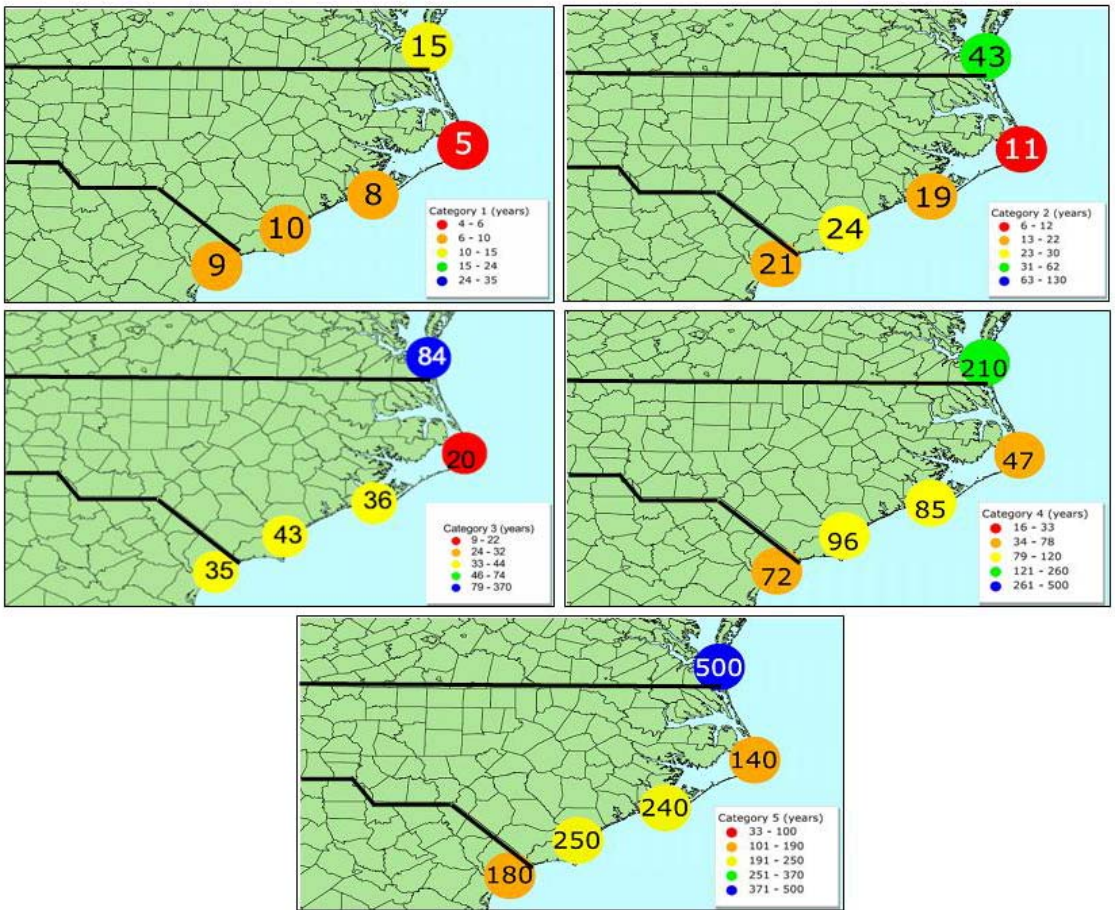

Figure XI-11. Expected Return Period of Hurricanes

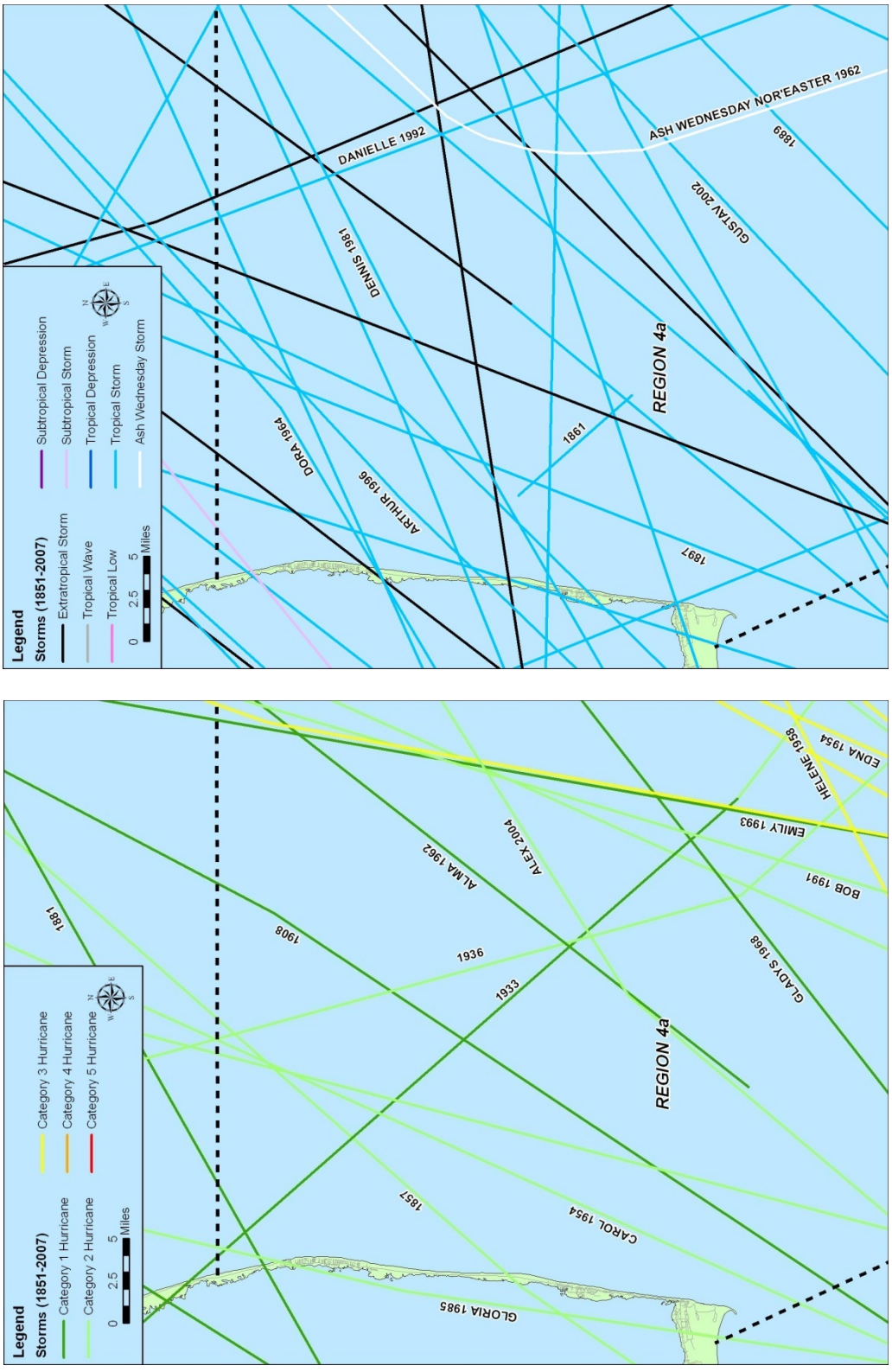

Figure XI-12. Atlantic Storm and Hurricane Tracks for Region 4a

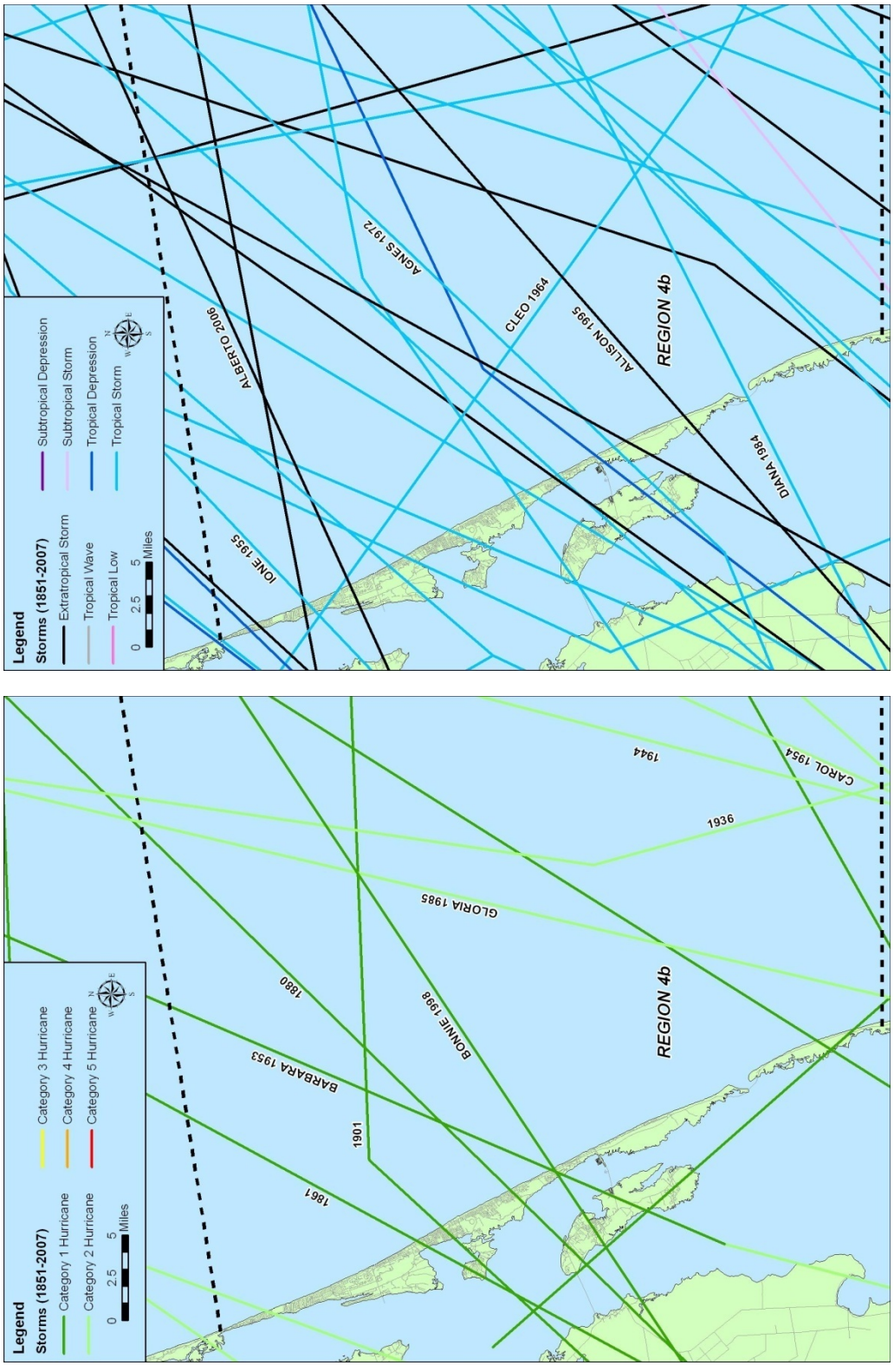

Figure XI-13. Atlantic Storm and Hurricane Tracks for Region 4b

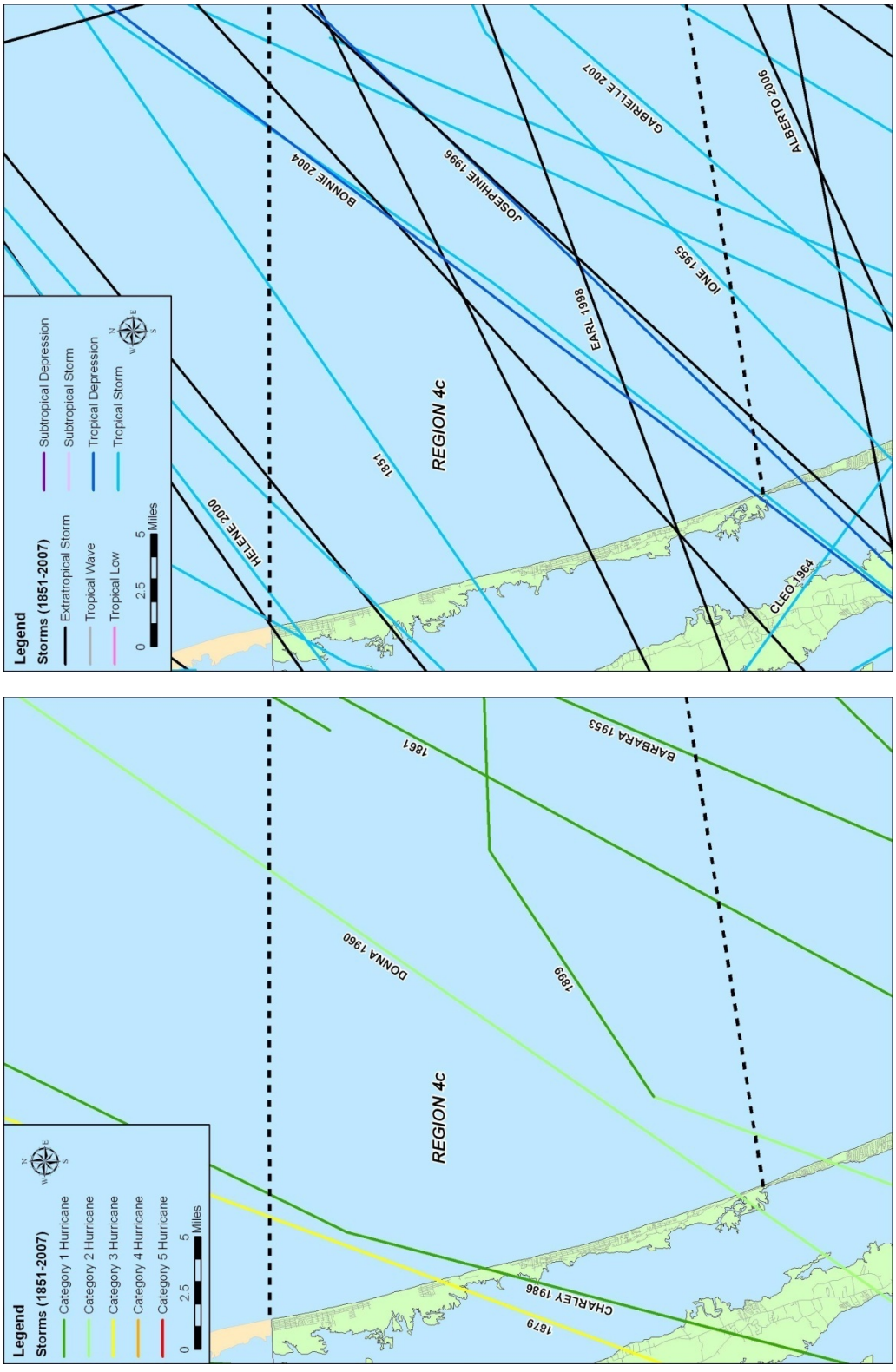

Figure XI-14. Atlantic Storm and Hurricane Tracks for Region 4c

3. Digital Orthophotography

Photography is available from various sources including the Division of Coastal Management (DCM), USGS, National Agriculture Imagery Program (NAIP), and individual county governments. Aerials of the entire oceanfront shoreline were taken in 1998 and 2004. In 2003, some post-Isabel aerials were taken of the ocean shoreline by USGS with the exception of Dare and Hyde counties. In 2006, the (NAIP) created mosaics for orthotiles for the entire coastline. Various counties also have oceanfront aerial photography for a variety of dates. Tables XI-11 to XI-13 identify the available digital orthophotography for Region 4.

Table XI-11. Digital Orthophotography for Region 4a

Oceanfront Photography (1998)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
1998	Hatteras Island @ Hatteras to Pea Island	Mr. SID	Tiles	B&W	DCM	.5'
Dare County (2002)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2002	Hatteras Island @ Hatteras to Kitty Hawk	Mr. SID	Tiles	Color	DCM	.25',1'
Oceanfront Photography (2004)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2004	Hatteras Isalnd @ Hatteras to Hatteras Island @ Salvo	Mr. SID	Mosaic	Color	DCM	.5'
2004	Hatteras Island @ Salvo to Bodie Island	Mr. SID	Mosaic	Color	DCM	.5'
NAIP Photography (2006)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2006	Dare County	Mr. SID	Mosaic	Color	NAIP	1'

Table XI-12. Digital Orthophotography for Region 4b

Oceanfront Photography (1998)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
1998	Bodie Island to Nags Head	Mr. SID	Tiles	B&W	DCM	.5'
1998	Hatteras Island @ Hatteras to Pea Island	Mr. SID	Tiles	B&W	DCM	.5'
1998	Nags Head to Dare County Line	Mr. SID	Tiles	B&W	DCM	.5'
Dare County (2002)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2002	Hatteras Island @ Hatteras to Kitty Hawk	Mr. SID	Tiles	Color	DCM	.25'
Oceanfront Photography (2004)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2004	Hatteras Island @ Salvo to Bodie Island	Mr. SID	Mosaic	Color	DCM	.5'
2004	Bodie Island to Kill Devil Hills	Mr. SID	Mosaic	Color	DCM	.5'
2004	Kill Devil Hills to Dare County Line	Mr. SID	Mosaic	Color	DCM	.5'
NAIP Photography (2006)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2006	Dare County	Mr. SID	Mosaic	Color	NAIP	1'

Table XI-13. Digital Orthophotography for Region 4c

Oceanfront Photography (1998)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
1998	Peter's Quarter to VA	Mr. SID	Tiles	B&W	DCM	.5'
Currituck County (2003)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2003	Currituck County	Mr. SID	Tiles	Color	DCM	2'
Oceanfront Photography (2004)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2004	Kill Devil Hills to Peters Quarter	Mr. SID	Mosaic	Color	DCM	.5'
2004	Peters Quarter to VA	Mr. SID	Mosaic	Color	DCM	.5'
NAIP Photography (2006)						
Date	**Coverage**	**Format**	**Mosaic/Tiles**	**Color**	**Source**	**Resolution**
2006	Currituck County	Mr. SID	Mosaic	Color	NAIP	1'

In addition, the USGS has Digital Orthophoto Quarter Quads (DOQQs) from 1998 for the entire coastline. These photos are Color Infrared MrSID images. MrSID, Multiresolution Seamless Image Database, is an image format developed for georeferenced raster graphics.

4. Historical Shorelines and Erosion Rates

In support of coastal planning efforts, DCM began developing a historical shoreline database starting in the 1970s. Shorelines were digitized for available years dating back to 1933. The primary source of historical data is the geo-referenced T-Sheets, provided by NOAA Coastal Services Center (CSC). DCM has also collaborated with the USGS and USACE to document the most recent shorelines based both on delineation of the wet-dry line as interpreted from orthophotography as well as deriving the Mean High Water Level (MHWL) based on LIDAR survey data. In addition to the statewide oceanfront shoreline datasets, DCM has compiled a historical shoreline database in the vicinity of inlets, varying in length on either side of the inlet from approximately 10,000 feet to the entire stretch of shoreline leading to the next inlet. Inlet shorelines were digitized and developed from multiple data sources including: North Carolina Department of Transportation rectified aerials, DCM orthophotos and NOAA CSC T-Sheets. Currently, inlet shorelines for Oregon Inlet are not available through DCM. Table XI-14 presents the available oceanfront shorelines which cover all three subregions of Region 4. GIS shape files of historical shorelines may be accessed via DCM's website at http://dcm2.enr.state.nc.us/Maps/chdownload.htm.

Table XI-14. Digitized NC Oceanfront Shorelines for Region 4

Oceanfront Shorelines			
Date	**Coverage**	**Type**	**Source**
1933-1952	NC Shoreline (Bird Island to Kill Devil Hills)	NOS T-Sheet (MHW)	DCM
1940-1962	NC Shoreline (Kill Devil Hills to VA)	Photo-Wet/Dry	DCM
1998	Entire NC Shoreline	Photo-Wet/Dry	DCM
2004	Entire NC Shoreline	NCDCM Photo-Wet/Dry	DCM
1849-1873	Entire NC Shoreline	NOS T-Sheet (MHW), CERC map	USGS, Coastal Carolina
1925-1946	Entire NC Shoreline	CERC map, USACE Photos, NOS T-Sheet (MHW)	USGS, NOAA, DCM
1970-1988	Entire NC Shoreline	CERC map, NOS T-Sheet (MHW)	USGS, NOAA, Coastal Carolina
1997	Entire NC Shoreline	LIDAR MHW Shoreline	USGS

Using the digitized shorelines, the N.C. Coastal Resources Commission (CRC) has established oceanfront development setbacks based on long-term shoreline change rates. Setback factors determine the distance back that development can be sited measured from the first line of stable and natural vegetation. Shoreline change has been calculated by DCM using the end-point method, based on the distance from the earliest shoreline archived by the state (varies for segments of shoreline but typically from the 1940s) to the most recent (1998) divided by the number of years between them. Erosion rates are calculated at 50m (164 ft) transects along shore. Raw rates are then "smoothed" to account for local variance and influences of inlets. DCM then determines setbacks based on these "smoothed erosion rates." Details regarding the methods used to conduct the most recent update of setback rates (based on the 1998 shoreline location) are documented by Overton and Fisher (March 2004). Figure XI-17 present the Long Term DCM erosion rates for all three subregions of Region 4.

Since inlets can temporarily interrupt and intercept the flow of sediments along the coast and migrate over time, they are typically areas of the greatest variation in erosion and accretion. This can be seen in the erosion rates plotted in Figures XI-15 to XI-17. The NCDOT hotspots at Buxton, Rodanthe, and Northern Pea Island are apparent with erosion rates greater than 10 feet per year. The Currituck National Wildlife Refuge also shows some significant erosion. There are some long-term accretional areas near Avon, Salvo, southern Pea Island, and near the North Carolina/Virginia border. In addition, the southern movement of Oregon Inlet is apparent, with accretional trends on the northern side of the inlet and erosional trends on the southern side of the inlet. The remainder of the shoreline shows neutral to moderate erosion.

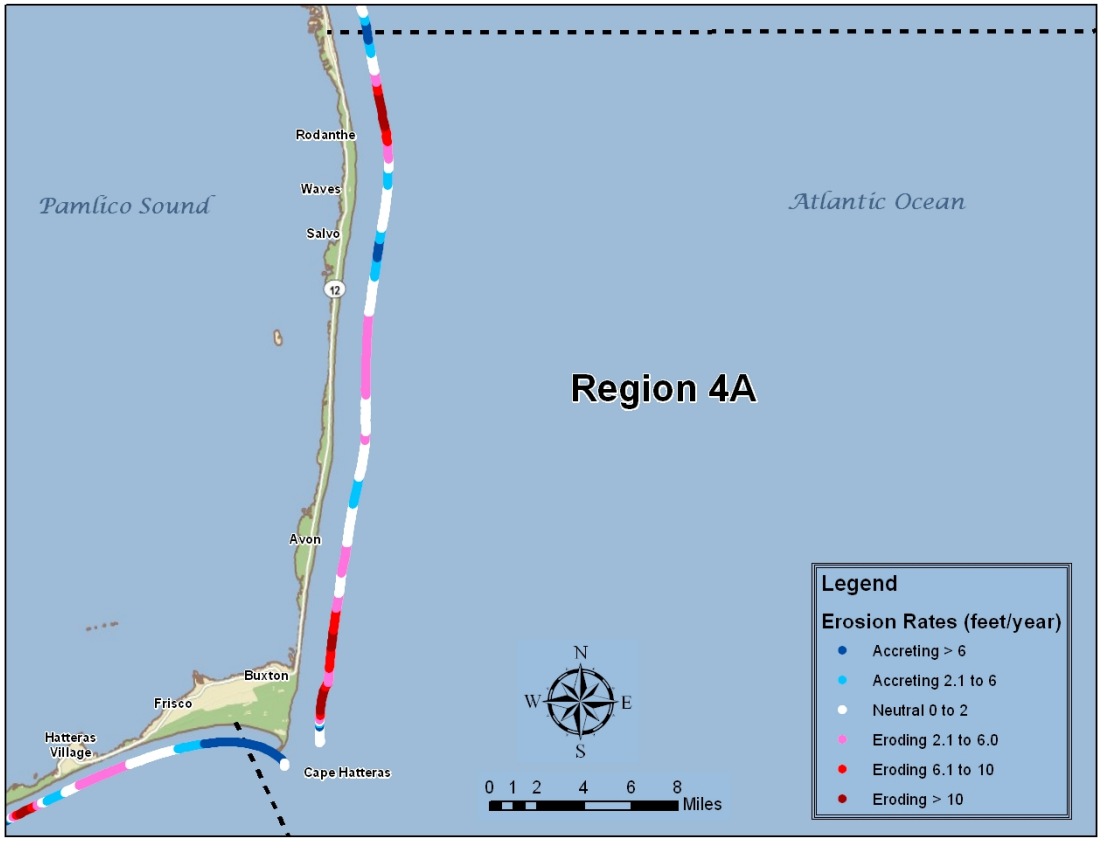

Figure XI-15. DCM Erosion Rates for Region 4a

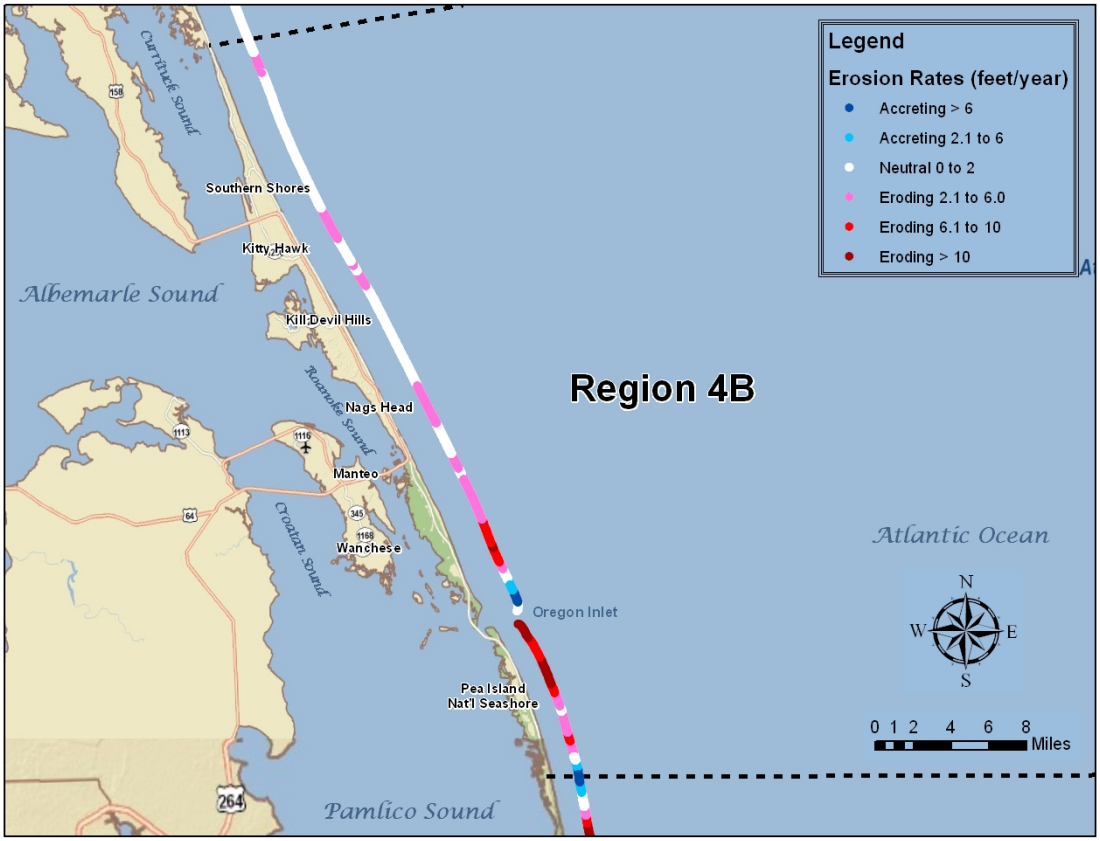

Figure XI-16. DCM Erosion Rates for Region 4b

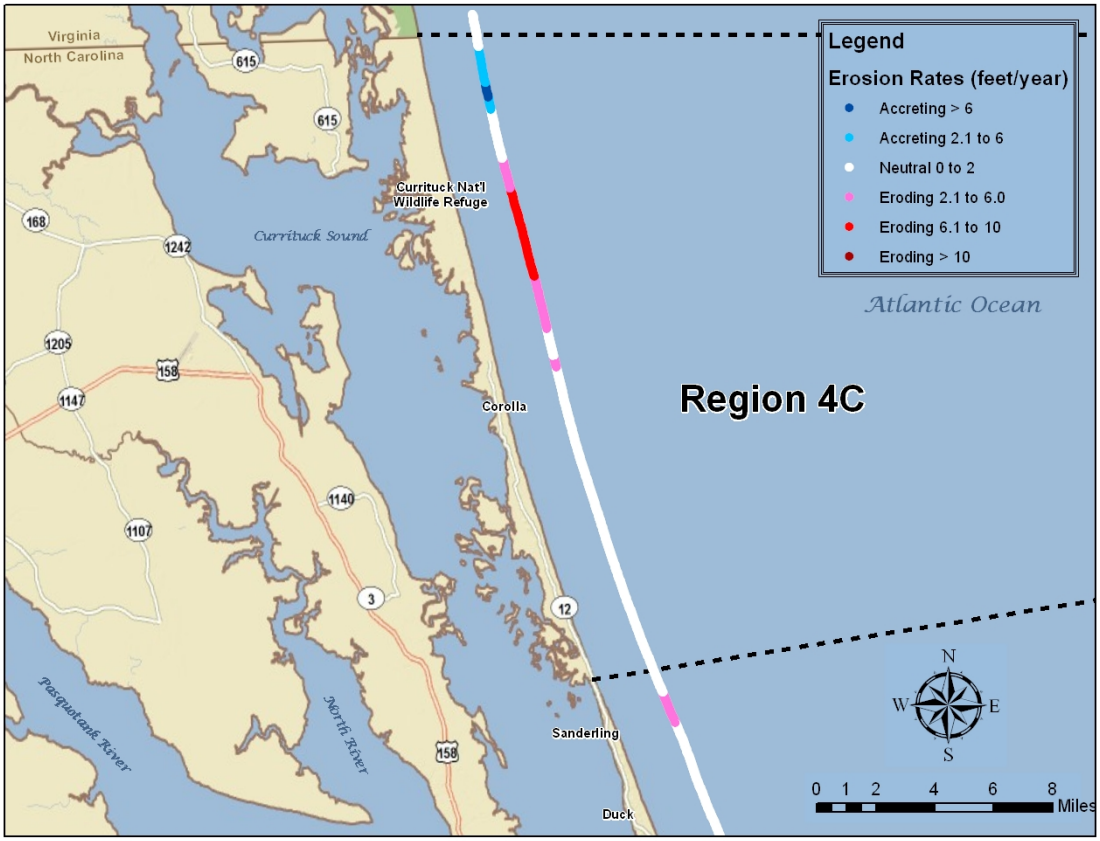

Figure XI-17. DCM Erosion Rates for Region 4c

5. Beach and Inlet Surveys

Beach profile data has been collected for several beaches along the North Carolina coast. This data is available in various formats depending on the location. Available beach profile data locations for the subregions of Region 4 are presented in Figure XI-18.

As part of the Dare County Physical Monitoring Program, beach profile data is available for the Bodie Island beaches of Southern Shores, Kitty Hawk, Kill Devil Hills, and Nags Head. The monitoring program included pre-, during-, and post-construction phases of a dune restoration project. Scheduled surveys were completed in August 2004, May 2005, May 2006, and October 2006. Surveys extend both onshore (dune to wading depth) and offshore (wading depth to approximately -30 feet NAVD88) and are taken at 144 transects which cover 27 miles of beach. In addition to regular monitoring, surveys are also performed if there is significant damage from a storm. For example, an additional survey was completed in November 2006 after a large storm event.

NCDOT also monitors Pea Island, conducting onshore beach surveys on a regular basis, multiple times per year. Dredge material from Oregon Inlet is often placed on the northern end of Pea Island since the terminal groin was constructed. Surveys on Pea

Island by NCDOT are intended to monitor the performance of the terminal groin and the nourishment received from the inlet. Surveys are often only performed to wading depth.

In addition to monitoring the beach through profile data, the Navigation Branch of the USACE Wilmington District maintains a database of hydrographic surveys for federal navigation channels. Surveys for Oregon Inlet can accessed via the USACE website at http://www.saw.usace.army.mil/nav/inlets.htm. This inlet is part of a federal dredge project to maintain the navigation channels at authorized dimensions.

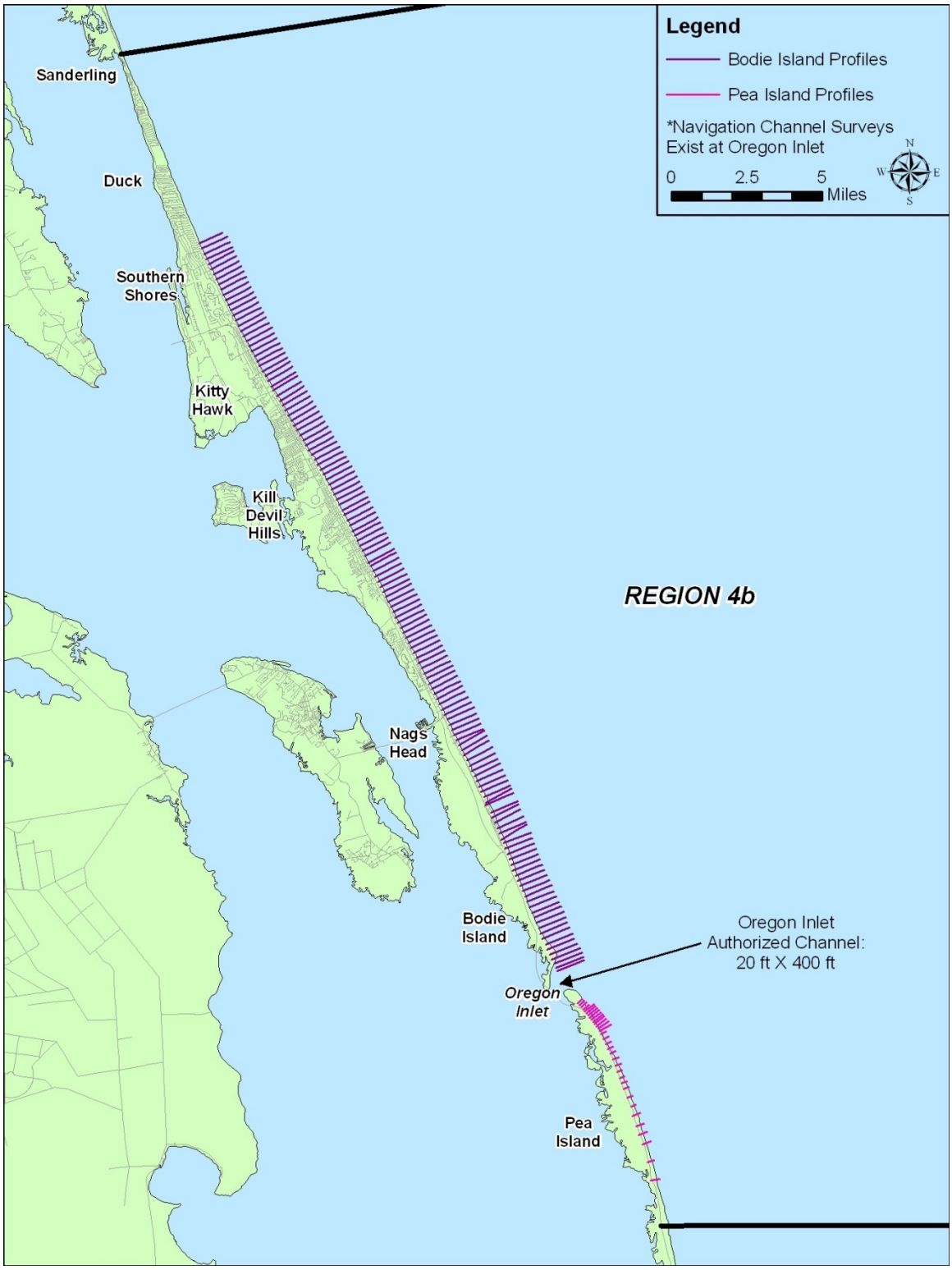

Figure XI-18. Beach Profile Monitoring Locations for Region 4b

6. Geologic Framework

The geological composition of the North Carolina coast and the dynamic nature of its inlets play a vital role in beach behavior and potential sources and availability of sand resources. Coastal geology – the origin, structure, and characteristics of coastal sediments, combined with the geological formation of the coastline over thousands of years of physical and chemical processes – dictates the properties of the sediments. The inlets provide a temporary natural disruption to longshore sediment transport and greatly impact sediment pathways. Coastal processes, of varying temporal and spatial scales, driven by water level changes, tides, waves, currents and winds interact with the local coastal geology and sediment supply to form and modify the configuration of the coastal region, forming features such as beaches, dunes, and inlets.

The gentler slopes of the Northern Province have long barrier islands and broad expanse of drowned river estuaries, which make up the Pamlico and Albemarle Sounds. The Pleistocene section within the Northern Province represents a complex record of multiple cycles of coastal deposition and erosion in response to numerous glacial-eustatic sea-level cycles (Riggs *et al.*, 1995). During glaciation sea level was considerably lower and the shoreline was seaward. Streams and rivers cut valleys into the land surface and previously deposited coastal systems. During subsequent transgression, as the ice sheets melted, sea level rose, drowning the river valleys and partially filling them with sediment. Thus, as Riggs *et al.* (1995) states, the modern barrier island system is stacked on top of numerous highly dissected, partially preserved lithostratigraphic units with irregular, erosional geometries and composed of sediments ranging from compact peat and mud to indurated sands and gravels.

The cycle of rising and falling sea levels and the associated river valleys, deposition, and reworking of sediments define this region with drowned estuary formations. Figure X-19 illustrates this paleodrainage system.

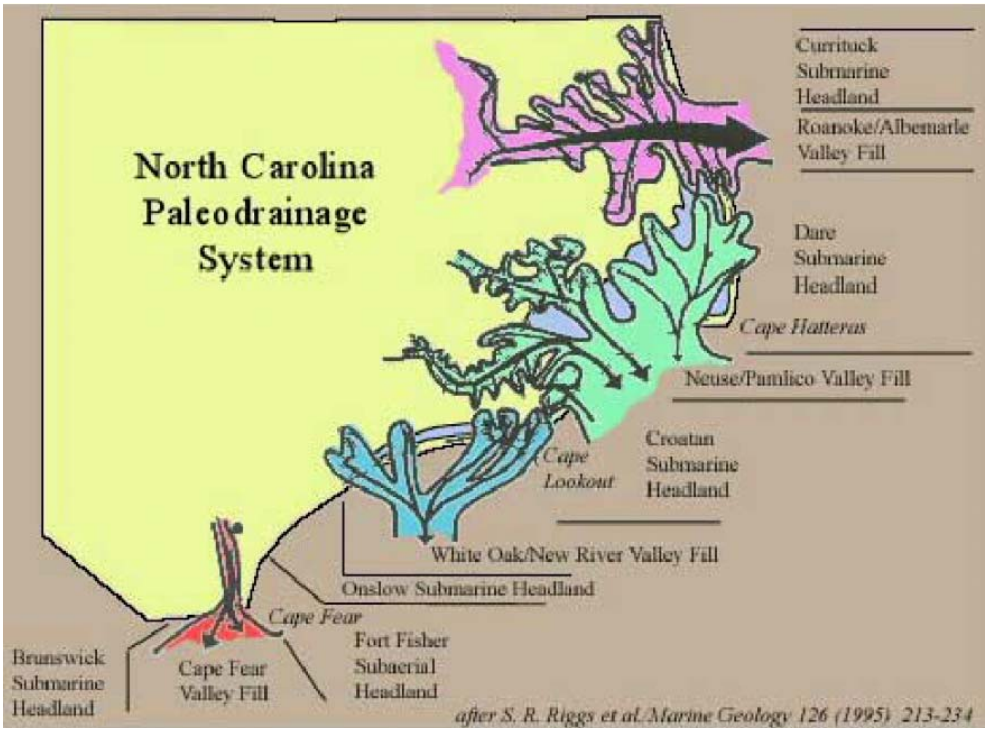

Figure XI-19. North Carolina's Paleodrainage System (Riggs *et al.*, 1995, Boss and Hoffman, 2001)

a) Region 4a Beaches

(1) Cape Hatteras National Seashore

The North Carolina Geological Survey (Hoffman *et al.*, 2007) produced a series of geomorphic maps of Cape Hatteras National Seashore from Ocracoke Island to Bodie Island. The geomorphic landform maps were developed from interpretation of several digital data layers and aided by field mapping. Data sets included LiDAR elevation data, digital imagery, DCM wetland mapping and shoreline maps among others. Figure XI-20 is an example of the mapping produced.

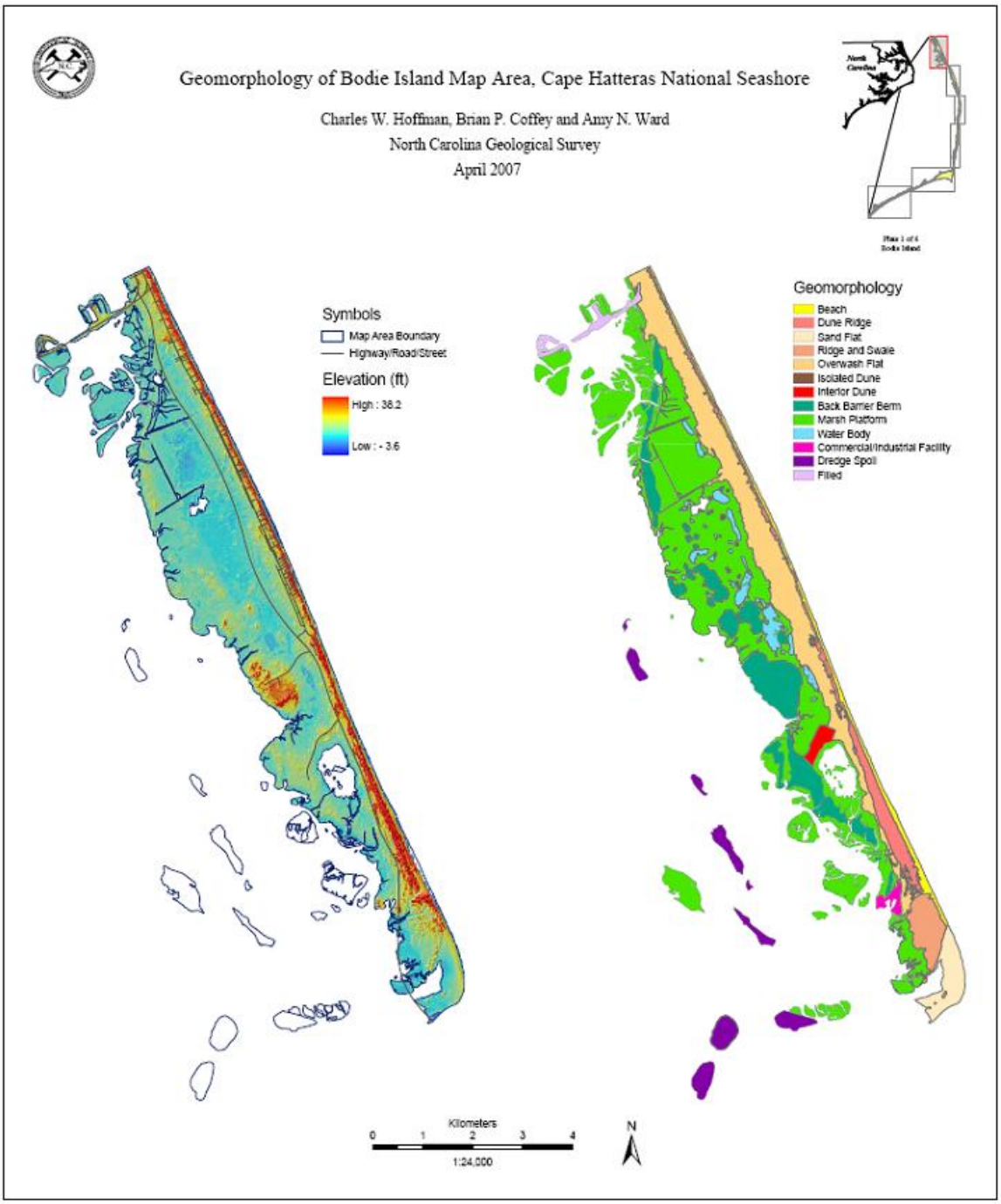

Figure XI-20. Geomorphic Mapping Example - Bodie Island

(2) Hatteras Island - Cape Hatteras to North of Rodanthe

This portion of Hatteras Island includes Cape Hatteras, Buxton, Avon, Salvo, Waves, and Rodanthe. Extending some 14 miles from Cape Hatteras to the southeast is a complex of sand bars and shallow water known as Diamond Shoals, which forms the northeastern end of Raleigh Bay. The shallow waters associated with this formation and numerous shipwrecks helped give the region the reputation as the "Graveyard of the Atlantic."

This segment of the Outer Banks is perched on a major ravinement surface cut into the front of the Dare Headland (figure XI-19), which defines the basic geometry of this portion of the Outer Banks (Riggs *et al.*, 1995). Riggs *et al.* (1995) observes that this region is characterized by the three coastal features:

1) A major change in barrier island orientation occurs at Rodanthe. The change in shoreline characteristics from Rodanthe to Cape Hatteras may be controlled by gently dipping Pleistocene sediments in the shallow subsurface along the southern edge of the Albemarle Basin.
2) A series of bathymetric highs occur on the inner shelf associated with each of several minor capes and intersect the lower beachface at acute angles. These include Wimble Shoals, which extend from Rodanthe to Salvo, and Kinnakeet Shoals. which extend from Kinnakeet to Avon. These shoals are made up of a series of ridges that are oriented north-northeast to south-southwest and have impacts on the energy regime affecting the adjacent beaches through wave refraction and wave setup.
3) In Pamlico Sound south of Rodanthe, the backside of the barrier island is characterized by the Hatteras Flats, a broad and very shallow platform bounded on the west by a vertical scarp up to 10 feet high.
4) Minor cape structures occur on the barrier beach at the towns of Rodanthe and Avon with rapidly receding beach segments occurring between the minor cape structures.

b) Region 4b Beaches and Inlets

(1) Pea Island

Pea Island National Wildlife Refuge is located on the north end of Hatteras Island between Oregon Inlet and the village of Rodanthe. It is part of a chain of coastal barrier islands that make up the Outer Banks and provide critical habitat for a wide variety of birds. Pea Island is approximately 13 miles long and ranges in width from a quarter to one mile. It is comprised of ocean beach, dunes, uplands, salt flats, salt marshes, and both fresh and brackish water ponds.

(2) Oregon Inlet

Oregon Inlet was opened by a major hurricane in September 1846 and separates Bodie Island from Pea Island in the south. It is the only inlet between Hatteras Inlet some 40 miles to the southwest and the more than 50-mile stretch to the end of Currituck Sound at the Virginia border. Currituck sound has no ocean inlet, so Oregon Inlet is the only outlet for the enormous volume of sound waters along this nearly 100-mile portion of the coast.

The inlet has experienced dynamic changes since its opening. Between 1846 and 1989, the inlet has migrated approximately two miles south of its original location (Mallinson *et al.*, 2008). The Herbert C. Bonner Bridge was constructed across the inlet in 1962. Since that time, numerous studies have been conducted on stabilizing the inlet and protecting the bridge. In an effort to help stabilize the inlet and protect the bridge and associated roadway from severe erosion, a terminal groin was built on the south side of the inlet in 1990. The shoals and channels continue to shift and the northern spit has continued to migrate to the south causing a narrowing and deepening of the inlet throat (Mallinson *et al.*, 2008). Changes in volume to the ebb-tidal delta appear to be cyclical and are related to the numerous storms that affect the area (Cleary and Marden, 1999).

(3) Outer Banks from Oregon Inlet to the Currituck County Border

The stratigraphic relationships within this region are spatially complex owing to the very low gradient, low-relief geomorphology and the Quaternary history of large amplitude sea level oscillations (Boss and Hoffman, 2001; Riggs and Ames, 2003). These oscillations resulted in multiple regressions and transgressions during which fluvial systems reestablished, and incised into coastal plain and continental shelf sediments. During subsequent transgression, fluvial valleys were inundated by rising sea levels and became the locus of fluvial sedimentation. The result of these numerous sea level oscillations was a complex mosaic of deposits of varying ages (Boss and Hoffman, 2001; Riggs and Ames, 2003). Riggs *et al.* (1995) cite an earlier study of profiles perpendicular to the shore by Pearson in 1979. These profiles extended from the shoreline to about three miles offshore and contained two major sediment units: a modern, thin shoreface sediment blanket over in situ relict sediments dominated by fluvial and back-barrier estuarine sediments deposited during previous sea-level events with the relict units ultimately cropped out on the inner shelf. The contact between the modern sand sheet and underlying relict units is erosional, with the most rapid rates of shoreline recession generally occurring in areas of old inlet and channel fill structures dominated by sand sediments.

The results of Boss and Hoffman's study (2001) of high-resoultion seismic reflection, side-scan sonar, and vibracore data clearly document the occurrence of a large paleofluvial system crossing the continental shelf offshore of Kill Devil Hills. This fluvial system was likely established during an episode or episodes of lower sea level when the continental shelf was emergent. The primary east-west trunk of the fluvial system corresponds to the ancestral Albemarle River drainage. The paleo-Albemarle

fluvial system was responsible for extensive erosion, reworking and redeposition. Figure XI-21 illustrates the location of this paleo-channel.

Relict and residual sediments are actively being eroded from the shoreface and deposited on the beach. Sections of the beach between Nags Head and the Virginia border contain abnormally high concentrations of quartz and lithoclast gravels occurring in areas where seismic data demonstrate the presence of paleofluvial channels passing beneath the barrier and cropping out on the adjacent continental shelf (Riggs *et al.*, 1995). The relationship of these paleo-channel formations with shore-oblique sandbars and gravel outcrops were also observed by Browder and McNinch (2006).

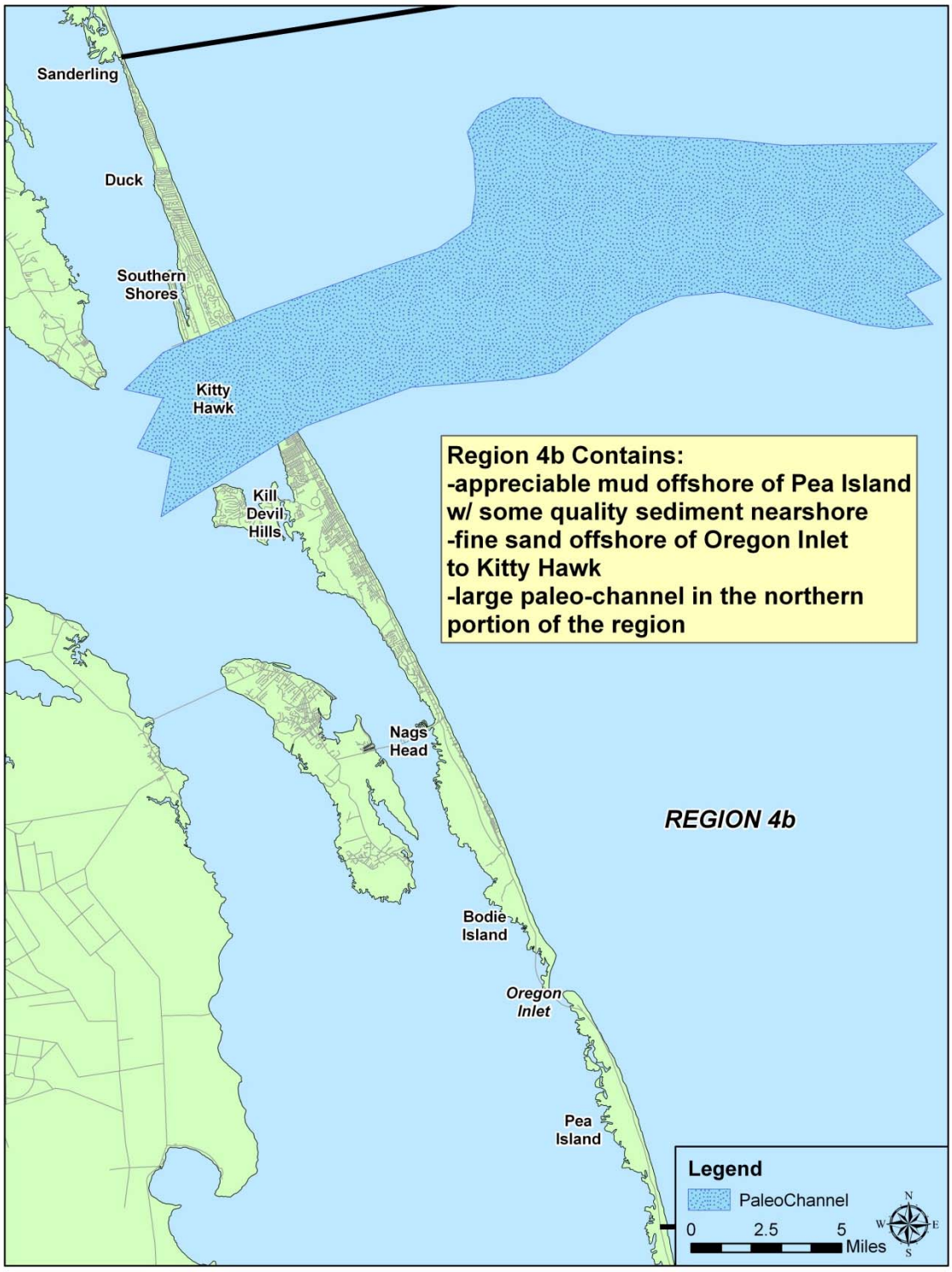

Figure XI-21. Geologic Framework for Region 4b

c) Region 4c Beaches

(1) Dare/Currituck County Line to the Virginia Border

This section of shoreline shares geologic characteristics of the Outer Banks north of Oregon Inlet described in the Region 4b portion of this section.

Part of this region is classified as a transgressive shoreface (Riggs *et al.*, 1995). A significantly large portion of the barrier islands are underlain by estuarine peat and mud deposits. As the barrier island systems migrated upward and westward in response to the general Holocene transgression, these old estuarine units were overrun. Deposits of estuarine peat and clay crop out in the surf zone along major portions of the North Carolina Outer Banks from Corolla to Southern Shores (Riggs *et al.*, 1995).

7. Sediment Budgets

Significant gaps exist in sediment transport and sediment budget information. The USACE has performed a sediment budget analysis around Oregon Inlet. In addition, Inman and Dolan have reviewed the general processes at work on the Outer Banks of North Carolina (Region 4). Conclusions from this research state that the barrier system moves as a whole, so that the sediment balance is relative to the moving shoreline. Specifically, Oregon Inlet is moving south, and there is an overall southerly longshore transport of sand (Inman and Dolan, 1989). The location of the available sediment budget for Region 4 is presented in Figure XI-22.

Figure XI-22. Available Sediment Budgets for Region 4b

8. Potential Sand Resources

Sand resources for beach nourishment projects come from both inlet dredging, offshore material deemed compatible with the beach, and offshore disposal sites containing previously dredged material. Potential sand resources are identified in various NCGS Open File Reports, USACE findings, USGS databases, and consulting firm investigations.

Region 4a has no inlets to be used as sediment sources. Several offshore sand sources in this region have been examined by the NCGS offshore of Cape Hatteras at Buxton and offshore between Rodanthe and Salvo. Note that these volume estimates are preliminary and subject to further field investigation.

Region 4b has one inlet (Oregon) which has been used as a source of sand for nearby beaches. In addition, the NCGS has examined many offshore sources for use in the Northern Dare County project and Nags Head nourishment (NCGS OFR01_02). The USACE has also established disposal islands in the sound for dredge material from Oregon Inlet and its associated channels.

Region 4c has limited sand source options. According the USGS SEABED database, there is a potential area offshore of the Currituck National Wildlife Refuge which contains material with an acceptable grain size for many North Carolina beaches (phi size=1.0-2.0 or 0.25 mm-0.5 mm). This area should be examined further to determine suitability.

Figures XI-23 to XI-25 show the potential sediment resources for all three subregions of Region 4.

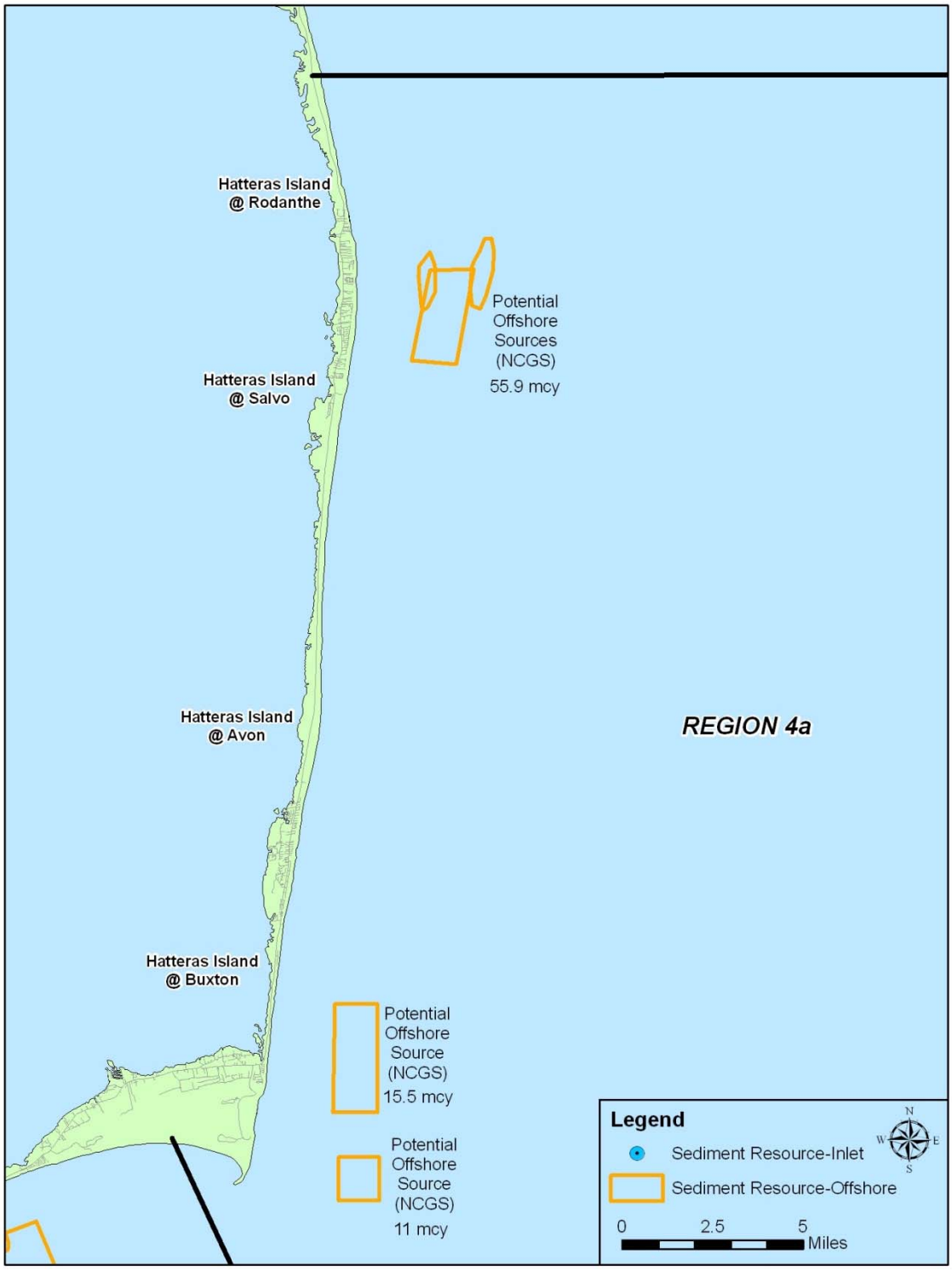

Figure XI-23 Potential Sediment Resources for Region 4a

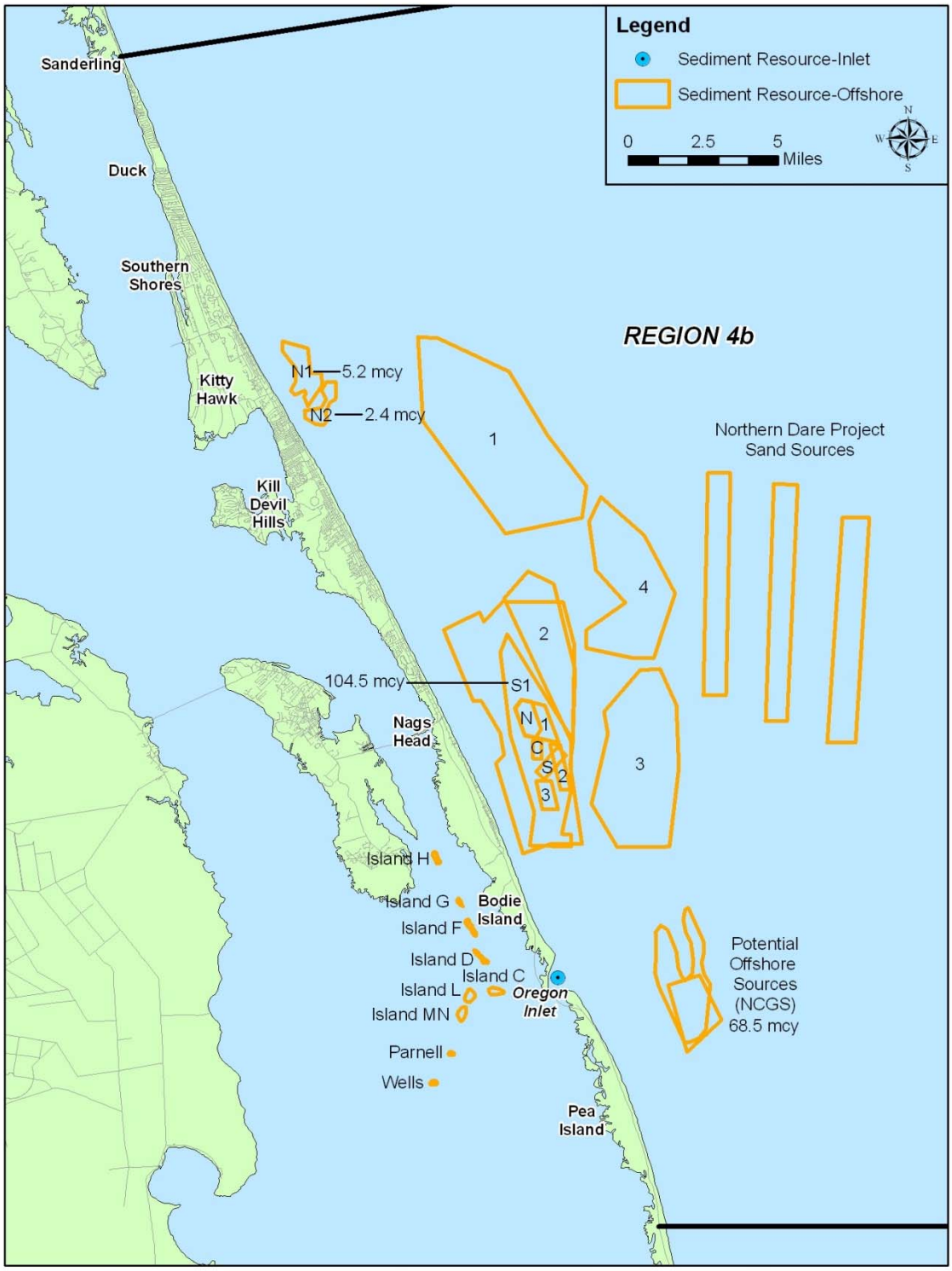

Figure XI-24. Potential Sediment Resources for Region 4b

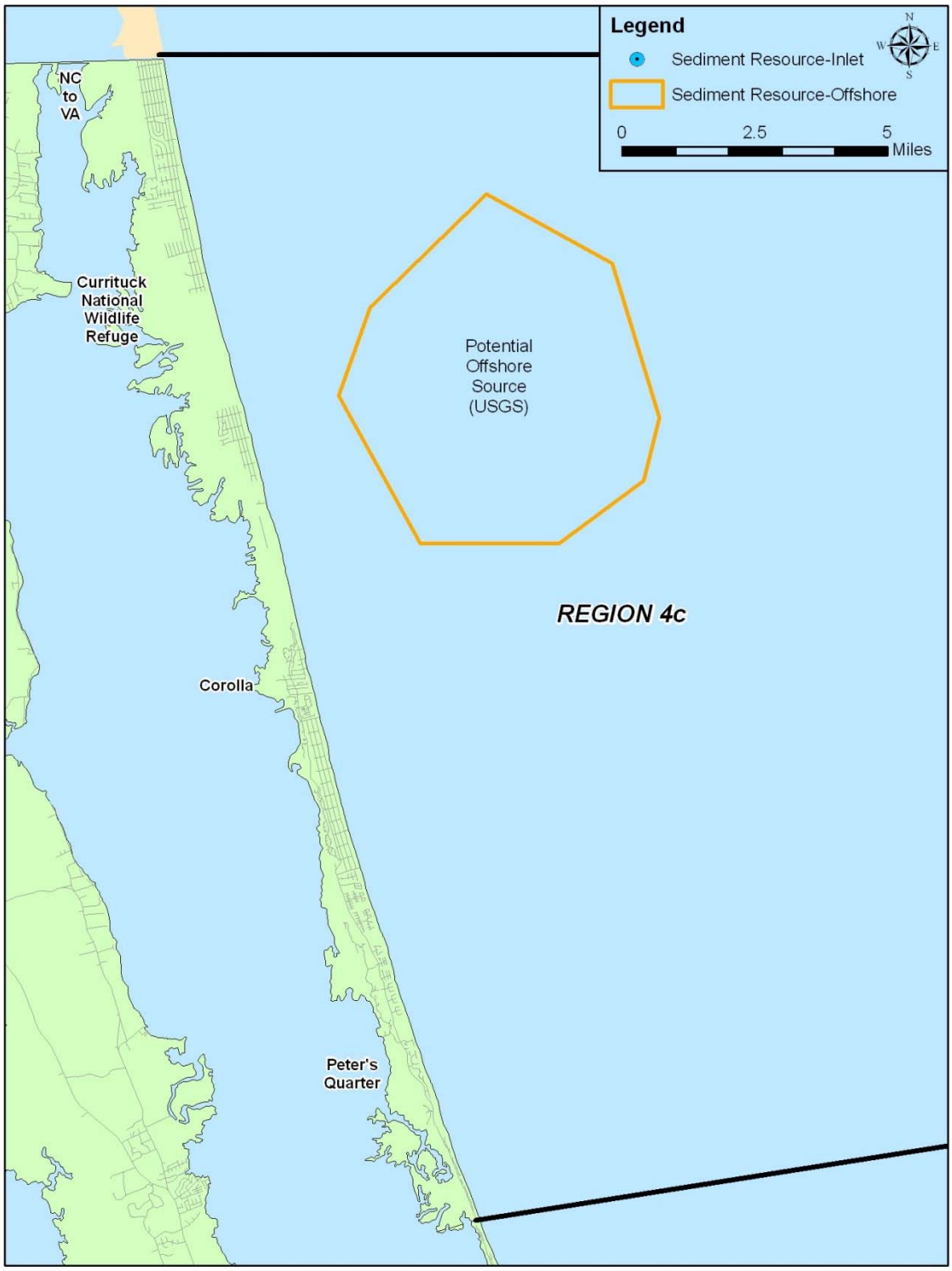

Figure XI-25. Potential Sediment Resources for Region 4c

9. Environmental Considerations

The BIMP recognizes environmental concerns as a vital part of holistic beach and inlet management strategies. Environmental considerations can be constraints on strategy choices, projects or timing of projects, but management strategies can also represent opportunities to preserve, restore, or create habitat. The N.C. Coastal Habitat Protection Plan (CHHP) identifies six primary habitats along coastal North Carolina that are vital to the health and function of North Carolina's coastal ecosystems and fisheries. The purpose of this section is to identify federally protected species, N.C. Natural Heritiage Program (NHP) Element Occurrences, Critical Habitats, and Significant Natural Heritage Areas. Site specific concerns for each beach and inlet in Region 4 are also identified. Appendix F contains maps of the primary coastal habitats as well as protected species and critical wildlife habitat mapping.

a) Region 4a - Federal Protected Species, NHP Element Occurrences, Critical Habitats, and Significant Natural Heritage Areas

- NHP identifies element occurrences for plant and animal species within Region 4a including the following species that could potentially occur within the identified project study area: seabeach amaranth, shortnose sturgeon, loggerhead sea turtle, green sea turtle, leatherback sea turtle, Kemp's ridley sea turtle, piping plover, and West Indian manatee. A site specific assessment and U.S. fish and Wildlife Service (USFWS) coordination should be conducted during project planning to avoid impacts to protected species.

- USFWS identifies May 1 – November 15 as the moratoria period for sea turtle nesting areas.

- Site specific sea turtle nesting data can be obtained from the N.C. Wildlife resources Commission (WRC) (http://www.seaturtle.org/nestdb/index.shtml?view=1).

- USFWS has not identified any critical habitat areas within Region 4a.

- Region 4a contains significant habitat for colonial water birds, wading birds and shore birds including known colonial wading bird colonies and gull-tern-skimmer colonies. All applicable USFWS and WRC moratoria should be observed.

- Site specific colonial water bird and shorebird data can be obtained from WRC.

- Site specific seabeach amaranth data can be obtained from USFWS and USACE as well as NHP.

b) Region 4a - Site Specific Concerns

The following details the environmental considerations specific to each beach/shoreline segment and inlet under the general headings of CHPP elements, protected species and wildlife elements, and any other notable considerations. The first section identifies elements related to the beach or inlet with respect to the CHPP. The second lists key protected species and wildlife issues and time of year restrictions on construction related activities. The third group, entitled "Other," lists any other environmental considerations, such as designated heritage or significant areas.

(1) Cape Hatteras

CHPP Elements

- Class SA waters in the Pamlico Sound
- Hard bottom well offshore
- Soft bottom habitat associated with shoals

Protected Species & Wildlife Elements

- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Colonial Waterbird nesting (April 1-August 31 moratoria in nesting areas)
- Loggerhead and green sea turtle nest sites (May 1-November 15 moratoria)
- Piping plover nesting (April 1-July 15 moratoria in nesting areas)
- Seabeach amaranth (will require surveys)
- Roseate tern
- Essential fish habitat (EFH) for 70 species south of Cape Hatteras; 39 species north of Cape Hatteras

Other

- Area of Regional and Federal Significance (Cape Hatteras National Seashore)
- High probability of shipwreck sites

(2) Hatteras Island at Buxton and Avon

CHPP Elements

- Class SA waters
- Salt marsh present sound side
- Extensive submerged aquatic vegetation (SAV) in Pamlico Sound
- Closed shellfish waters near Buxton and Avon; open elsewhere

Protected Species & Wildlife Elements

- Loggerhead and green sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Colonial waterbird nesting (April 1-August 31 moratoria in nesting areas)
- West Indian manatee occurrence (June – October moratoria; observers possibly required)
- Seabeach amaranth (has not been observed by USACE in at least five years)
- EFH for 39 species (Atlantic Ocean)

Other
- Area of Regional and Federal Significance (Cape Hatteras National Seashore)

(3) Hatteras Island at Salvo and Rodanthe

CHPP Elements
- Class SA waters
- Abundant salt marsh along sound side
- Extensive SAV in sound
- Mostly open shellfish waters
- Hard bottom within three to four miles from beach

Protected Species & Wildlife Elements
- Loggerhead and green sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Colonial waterbird nesting (April 1-August 31 moratoria in nesting areas)
- West Indian manatee occurrence (June – October moratoria; observers possibly required)
- Seabeach amaranth (has not been observed by USACE in at least five years)

Other
- Areas of State, Regional & Federal Significance (Cape Hatteras National Seashore)

Figure XI-26 presents a sample of the environmental considerations which are present in Region 4a.

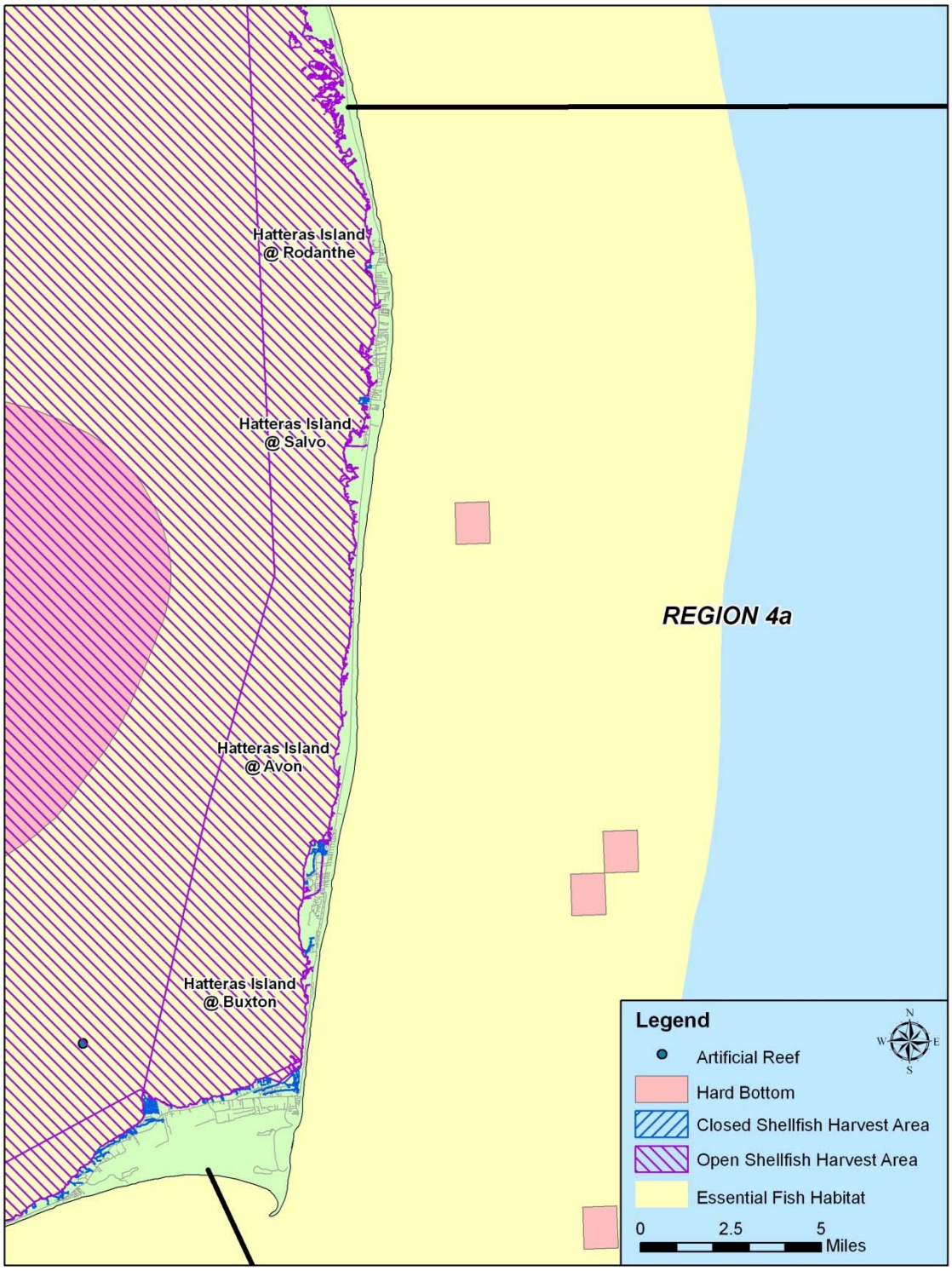

Figure XI-26. Sample Environmental Considerations for Region 4a

c) Region 4b - Federal Protected Species, NHP Element Occurrences, Critical Habitats, and Significant Natural Heritage Areas

- NHP identifies element occurrences for plant and animal species within Region 4b including the following species that could potentially occur within the identified project study area: seabeach amaranth, shortnose sturgeon, loggerhead sea turtle, green sea turtle, leatherback sea turtle, Kemp's Ridley sea turtle, piping plover, and West Indian manatee. A site specific assessment and USFWS coordination should be conducted during project planning to avoid impacts to protected species.

- USFWS identifies May 1 – November 15 as the moratoria period for sea turtle nesting areas.

- Site specific sea turtle nesting data can be obtained from the WRC (http://www.seaturtle.org/nestdb/index.shtml?view=1).

- USFWS has not identified any critical habitat areas within Region 4b.

- Region 4b contains significant habitat for colonial water birds, wading birds and shore birds including known colonial wading bird colonies and gull-tern-skimmer colonies. All applicable USFWS and WRC moratoria should be observed.

- Site specific colonial water bird and shorebird data can be obtained from the WRC.

- Site specific seabeach amaranth data can be obtained from USFWS and USACE as well as NHP.

d) Shipwrecks

An assessment was made for the potential of the inlets and surrounding areas in Region 4b to contain underwater shipwrecks. Time periods assessed included the sixteenth and seventeenth centuries, the eighteenth and early nineteenth centuries, the Civil War, and the late nineteenth and twentieth centuries. Four categories of potential for underwater shipwrecks are given: low, moderate, high, and general:

- Low potential means that the area around the inlet has little potential to contain shipwrecks from that time period.
- Moderate potential means it is known the inlet was used by shipping during that time period and that wrecks from that time period are present in the area.

- High potential means that the inlet witnessed high volumes of ship traffic during that time period and that wrecks from that time period are present in the area.
- General potential means that shipping traffic used the inlet during that time period, but the volume and presence of wrecks in the area cannot be categorized.

Note that shipwrecks are only listed in the following sections if there is a high probability of encountering them based on available data. Mapping of shipwrecks and other cultural resources is not as complete as needed for detailed assessments.

e) Region 4b - Site Specific Concerns

The following details the environmental considerations specific to each beach/shoreline segment and inlet under the general headings of CHPP elements, protected species and wildlife elements, and any other notable considerations. The first section identifies elements related to the beach or inlet with respect to the CHPP. The second lists key protected species and wildlife issues and time of year restrictions on construction related activities. The third group entitled "Other" lists any other environmental considerations, such as designated heritage or significant areas.

(1) Pea Island

CHPP Elements

- Class SA waters
- Extensive salt marsh along sound and interior wetland areas
- Abundant SAV in sound
- Open shellfish waters
- Hard bottom approximately two miles off beach
- Artificial reef offshore

Protected Species & Wildlife Elements

- Loggerhead and green sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Colonial waterbird nesting (April 1-August 31 moratoria in nesting areas)
- Piping plover nesting (April 1-July 15 moratoria in nesting areas)
- Seabeach amaranth (will require surveys)
- Crab spawning sanctuary at Oregon Inlet
- EFH for 15 species in Pamlico Sound; 39 in Atlantic Ocean

Other

- Area of Regional and Federal Significance (Cape Hatteras National Seashore)
- Pea Island National Wildlife Refuge

(2) Oregon Inlet

CHPP Elements
- Class SA waters
- Open shellfish waters
- Abundant SAV inside inlet to north and south
- Hard bottom approximately 4.5 miles southeast of inlet; artificial reef also
- Soft bottom habitat possibly present with ebb-tidal delta

Protected Species & Wildlife Elements
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Colonial waterbird nesting (April 1-August 31 moratoria in nesting areas)
- Piping plover nesting (April 1-July 15 moratoria in nesting areas)
- Crab spawning sanctuary at Oregon Inlet
- Sea turtle habitat (limit takes during dredging)
- EFH for 27 species
- WRC (Island C in Oregon Inlet)

Shipwrecks
- Potential for 18th and early 19th century shipwrecks
- Low potential for Civil War shipwrecks
- Moderate potential for late 19th and 20th century shipwrecks
- Underwater archaeological survey work conducted for proposed Bonner Bridge replacement

Other
- Area of Regional and Federal Significance (Cape Hatteras National Seashore)
- Areas of State Significance inside inlet consisting of several islands for wildlife
- Pea Island National Wildlife Refuge located to the south of inlet
- N.C. Wildlife Resources Commission islands (Old-House Channel, Island L and Island MN) inside Oregon Inlet

(3) Bodie Island

CHPP Elements
- Class SA waters
- Open shellfish waters except near US Coast Guard station
- Extensive wetlands on Bodie Island sound side
- SAV in south end of Roanoke Sound
- Hard bottom more than five miles offshore

Protected Species & Wildlife Elements
- Loggerhead and green sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Colonial waterbird nesting (April 1-August 31 moratoria in nesting areas)
- Piping plover nesting (April 1-July 15 moratoria in nesting areas)
- Seabeach amaranth (has not been observed by USACE in at least five years)

- Crab spawning sanctuary at Oregon Inlet and along south end of Bodie Island
- EFH for 15 species in Pamlico Sound; 39 species in Atlantic

Other
- Area of State, Regional, and Federal Significance (Cape Hatteras National Seashore)

(4) Nags Head

CHPP Elements
- Class SA waters
- Some SAV along shoreline of the sound
- Few interior wetlands
- Mixture of open and closed shellfish waters
- Hard bottom within two miles of the beach

Protected Species & Wildlife Elements
- Loggerhead and green sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Bald eagle
- Colonial waterbird nesting (April 1-August 31 moratoria in nesting areas)
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 15 species in Pamlico Sound; 39 species in Atlantic

Other
- Area of Regional and State Significance (Jockey's Ridge)

(5) Kill Devil Hills

CHPP Elements
- Class SA waters
- Salt marsh along sound; some interior wetlands
- SAV along shoreline of the sound
- Open waters in the sound; closed waters in Buzzard Bay
- Hard bottom and artificial reef > more than five miles offshore

Protected Species & Wildlife Elements
- Loggerhead and green sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Bald eagle
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 15 species in Pamlico Sound; 39 species in Atlantic

Other
- Areas of Federal and National Significance (Wright Brothers Memorial)

(6) Kitty Hawk

CHPP Elements
- Closed shellfish waters in Kitty Hawk Bay
- Extensive coastal marsh around Kitty Hawk Bay; some interior wetlands
- Extensive SAV around Kitty Hawk Bay
- Hard bottom and artificial reef more than five miles offshore

Protected Species & Wildlife Elements
- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Bald eagle
- West Indian manatee occurrence (June –October moratoria; observers possibly required)
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 15 species in Pamlico Sound; 39 species in Atlantic

Other
- Area of county and state significance in Kitty Hawk Bay

(7) Southern Shores

CHPP Elements
- Extensive wetlands along sound
- Some SAV along sound shoreline
- Open shellfish waters in Currituck Sound; closed waters in Jean Guite Creek

Protected Species & Wildlife Elements
- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- West Indian manatee occurrence (June – October moratoria; observers possibly required)
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 11 species in Currituck Sound; 39 species in Atlantic

(8) Duck

CHPP Elements
- Open waters in Currituck Sound
- Little SAV along shoreline of the sound
- Few wetlands present

Protected Species & Wildlife Elements
- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- West Indian manatee occurrence (June – October moratoria; observers possibly required)
- Seabeach amaranth (presence unlikely, but will require surveys)

- EFH for 11 species in Currituck Sound; 39 species in Atlantic

(9) Sanderling

CHPP Elements

- Closed shellfish waters in this part of the Currituck Sound
- Extensive SAV in Currituck Sound adjacent to Sanderling

Protected Species & Wildlife Elements

- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 11 species in Currituck Sound; 39 species in Atlantic

Figure XI-27 presents a sample of the environmental considerations which are present in Region 4b.

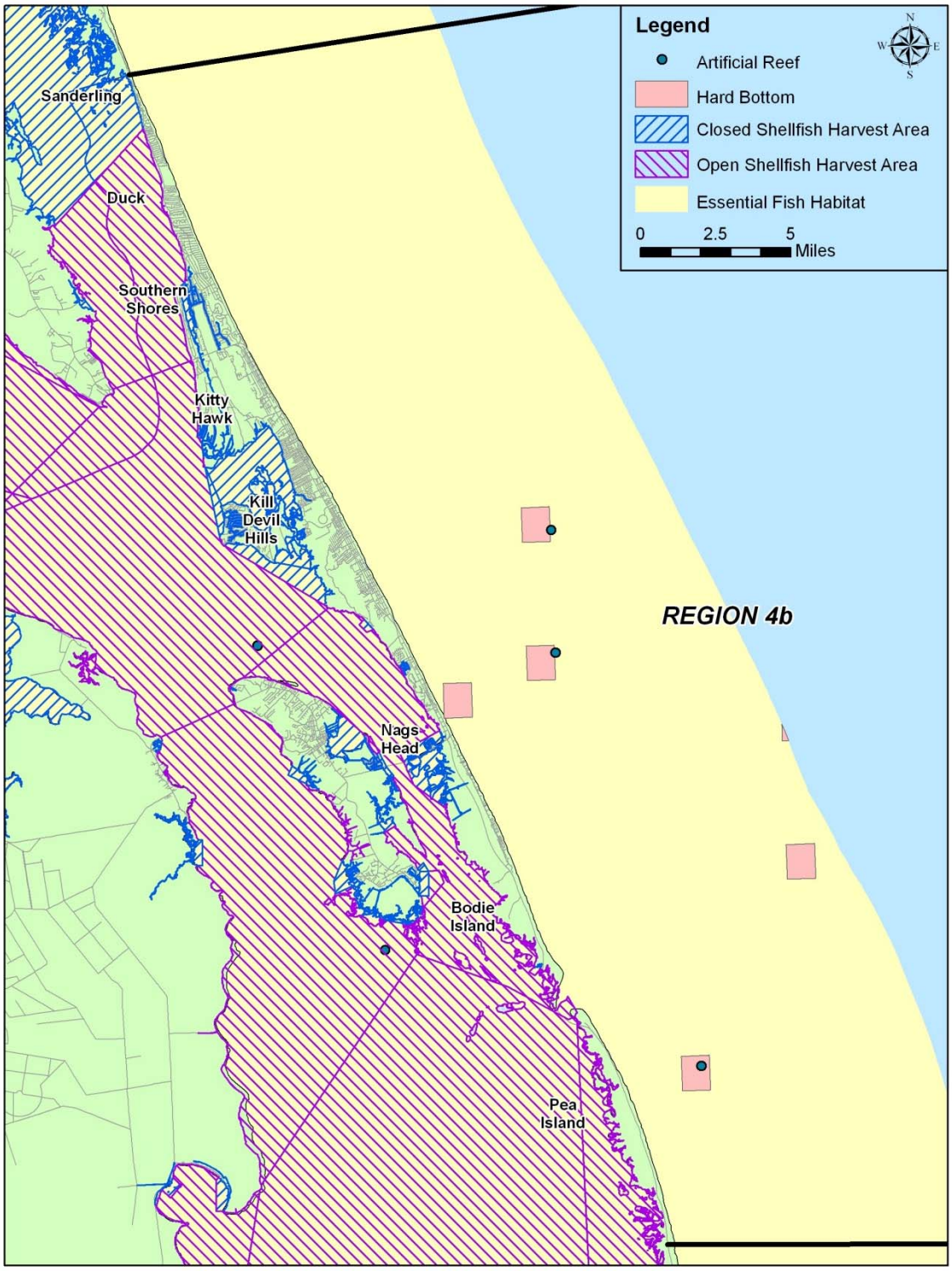

Figure XI-27. Sample Environmental Considerations for Region 4b

f) Region 4c - Federal Protected Species, NHP Element Occurrences, Critical Habitats, and Significant Natural Heritage Areas

- NHP identifies element occurrences for plant and animal species within Region 4c including the following species that could potentially occur within the identified project study area: seabeach amaranth, shortnose sturgeon, loggerhead sea turtle, leatherback sea turtle, piping plover, and West Indian manatee. A site specific assessment and USFWS coordination should be conducted during project planning to avoid impacts to protected species.

- USFWS identifies May 1 – November 15 as the moratoria period for sea turtle nesting areas.

- Site specific sea turtle nesting data can be obtained from WRC (http://www.seaturtle.org/nestdb/index.shtml?view=1).

- USFWS has not identified any critical habitat areas within Region 4c.

- Region 4c contains significant habitat for colonial water birds, wading birds and shore birds including known colonial water bird colonies and gull-tern-skimmer colonies. All applicable USFWS and WRC moratoria should be observed.

- Site specific colonial water bird and shorebird data can be obtained from WRC.

- Site specific seabeach amaranth data can be obtained from USFWS and USACE as well as NHP.

- Region 4c contains several significant natural heritage areas based on current NHP data. Some of the estuarine sites include, but are not limited to, Currituck Banks/Corolla Natural Area, Swan Island Natural Area, Pine Island, Great Marsh and Monkey Island Heronry. Monkey Island Heronry is one of North Carolina's best wading bird rookeries and is part of the Currituck National Wildlife Refuge. Significant natural heritage sites located in he Albemarle Sound Region includes Mamie Marshes and Ponds, Harbinger Marshes, Church Island Marsh, Maple Swamp, and Bell Point Marsh.

g) Region 4c - Site Specific Concerns

The following details the environmental considerations specific to each beach/shoreline segment and inlet under the general headings of CHPP elements, protected species and wildlife elements, and any other notable considerations. The first section identifies elements related to the beach or inlet with respect to the CHPP. The second lists key protected species and wildlife issues and time of year restrictions on construction related activities. The third group, entitled "Other," lists any other environmental considerations, such as designated heritage or significant areas.

(1) Peter's Quarter

CHPP Elements
- Closed shellfish waters
- Abundant SAV in Currituck Sound
- Expansive marsh on sound side
- Numerous interior wetlands

Protected Species & Wildlife Elements
- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 11 species in Currituck Sound; 39 species in Atlantic

Other
- Area of Regional and State Significance associated with sound side marshes

(2) Corolla

CHPP Elements
- Closed shellfish waters
- Abundant SAV in sound
- Extensive coastal marsh along sound; interior wetlands present

Protected Species & Wildlife Elements
- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 11 species in Currituck Sound; 39 species in Atlantic

(3) Currituck National Wildlife Refuge

CHPP Elements
- Closed shellfish waters
- Extensive wetlands along sound
- Abundant SAV in sound

Protected Species & Wildlife Elements
- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Seabeach amaranth (presence unlikely, but will require surveys)
- Piping plover nesting (April 1-July 15 moratoria in nesting areas)
- Colonial waterbird nesting (April 1-August 31 moratoria in nesting areas)
- EFH for 11 species in Currituck Sound; 39 species in Atlantic

Other
- Area of State and Federal Significance (Currituck National Wildlife Refuge)

(4) NC to VA (Wildlife Refuge to VA Border)

CHPP Elements
- Closed shellfish waters
- Extensive wetland areas along sound
- Abundant SAV in sound

Protected Species & Wildlife Elements
- Loggerhead sea turtle nest sites (May 1-November 15 moratoria)
- Shortnose sturgeon occurrence (February 1-June 15 moratoria)
- Seabeach amaranth (presence unlikely, but will require surveys)
- EFH for 11 species in Currituck Sound; 39 species in Atlantic

Other
- Areas of State and Federal Significance

Figure XI-28 presents a sample of the environmental considerations which are present in Region 4c.

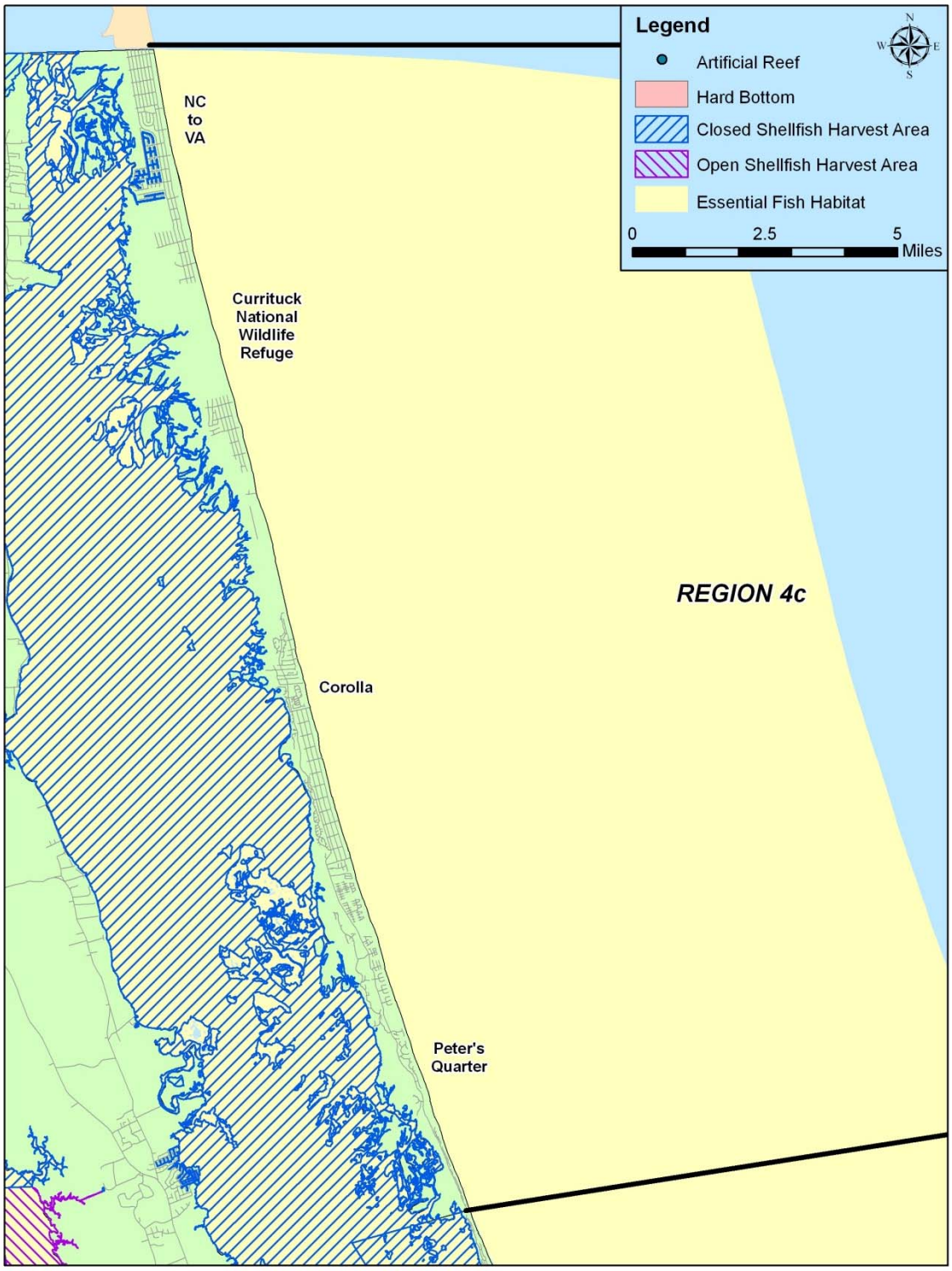

Figure XI-28. Sample Environmental Constraints for Region 4c

10. Economic Valuation

a) Property Value At Risk

Tables XI-15 and XI-16 provide the value of property at risk from sea level rise for Region 4. Estimates were based on Bin *et al.* (2007) with a sea level rise scenario of 18.1 in (46 cm) by 2080. As outlined in Chapter IV, the CRC Science Panel on Coastal Hazards released a report with a likely range of sea level rise that should be adopted for policy development and planning purposes. The Science Panel found the most likely scenario for 2100 AD is a rise of 0.4 meter to 1.4 meters (15 inches to 55 inches) above present. In comparison to the BIMP scenarios presented in Table IV-1, the Science Panel ranges represent a rise in sea level between 0.29 and 1.02 feet by 2030 and between 1.02 and 3.57 feet by 2080. In addition, the North Carolina Sea Level Rise Risk Management Study being carried out by the N.C. Division of Emergency Management is ongoing with final scenarios expected in mid-2011.

Values are provided in the original study dollars (2004) and adjusted to 2008 year-equivalent dollars. Currituck County (Region 4c) was not included in the Bin *et al.* (2007) study. This county should be included in future studies.

Table XI-15. Property Value At Risk From Sea Level Rise – Region 4a and 4b

Coastal Region	County	Beach	Value of Residential Coastal Property at Risk 2004	Value of Commercial Coastal Property at Risk 2004	Value of Residential Coastal Property at Risk 2008	Value of Commercial Coastal Property at Risk 2008
4a, 4b	Dare	All	$906,700,000	$1,318,100,000	$981,949,506	$1,427,492,715

Table XI-16. Property Value At Risk From Sea Level Rise – Region 4c

Coastal Region	County	Beach	Value of Residential Coastal Property at Risk 2004	Value of Commercial Coastal Property at Risk 2004	Value of Residential Coastal Property at Risk 2008	Value of Commercial Coastal Property at Risk 2008
4c	Currituck	All	N/A	N/A	N/A	N/A

b) Beach Recreation

The direct annual expenditures and the associated employment and estimated total economic impact including multiplier effects are presented in Tables XI-17 to XI-19 along with the consumer surplus value of beach recreation. The data has been aggregated to a beach segment level for the region.

Table XI-17. Beach Recreation Values – Region 4a

Coastal Region	County	Beach	Beach Recreation 2005-2006 Total Impact Employment (jobs)	Beach Recreation 2008 Annual Direct Expenditures	Beach Recreation 2008 Annual Total Impact Output/ Sales/ Business Activity	Beach Recreation 2008 Annual Consumer Surplus
4a	Dare	Hatteras Island @ Buxton & Frisco	949	$41,344,362	$73,255,139	$1,464,527
4a	Dare	Hatteras Island @ Avon	905	$39,400,531	$69,811,004	$1,433,301
4a	Dare	Hatteras Island @ Salvo & Waves	426	$18,555,354	$32,876,914	$861,026
4a	Dare	Hatteras Island @ Rodanthe	497	$21,647,912	$38,356,399	$1,004,530
REGION 4a TOTALS=			2,777	$120,948,158	$214,299,456	$4,763,384

Table XI-18. Beach Recreation Values – Region 4b

Coastal Region	County	Beach	Beach Recreation 2005-2006 Total Impact Employment (jobs)	Beach Recreation 2008 Annual Direct Expenditures	Beach Recreation 2008 Annual Total Impact Output/ Sales/ Business Activity	Beach Recreation 2008 Annual Consumer Surplus
4b	Dare	Pea Island	N/A	N/A	N/A	N/A
4b	Dare	Nags Head	3534	$153,930,507	$272,738,538	$7,718,678
4b	Dare	Kill Devil Hills	2770	$120,623,632	$213,724,451	$5,878,235
4b	Dare	Kitty Hawk	2216	$96,498,906	$170,979,561	$4,702,588
4b	Dare	Southern Shores	369	$16,079,625	$28,490,346	$490,769
4b	Dare	Duck	913	$39,775,412	$70,475,229	$1,267,071
4b	Dare	Sanderling	536	$23,339,424	$41,353,469	$744,153
REGION 4bTOTALS=			10,338	$450,247,505	$797,761,593	$20,801,495

Table XI-19. Beach Recreation Values – Region 4c

Coastal Region	County	Beach	Beach Recreation 2005-2006 Total Impact Employment (jobs)	Beach Recreation 2008 Annual Direct Expenditures	Beach Recreation 2008 Annual Total Impact Output/ Sales/ Business Activity	Beach Recreation 2008 Annual Consumer Surplus
4c	Currituck	Peters Quarter	1775	$81,648,411	$127,474,850	$3,395,149
4c	Currituck	Corolla	1409	$64,789,963	$101,154,336	$2,694,132
4c	Currituck	Currituck National Wildlife Refuge	N/A	N/A	N/A	N/A
4c	Currituck	Refuge to VA	582	$26,774,827	$41,802,615	$1,113,366
REGION 4cTOTALS=			3,767	$173,213,201	$270,431,801	$7,202,646

c) Shore and Pier Fishing

In addition to beach recreation value, people attach value to fishing from the shore and from pier structures. This value, defined here as consumer surplus, is presented in Table XI-20 to XI-22 for the Region 4 beaches.

Table XI-20. Shore and Pier Fishing – Region 4a

Coastal Region	County	Beach	Annual Pier/Bridge/Jetty Fishing Consumer Surplus (2008)	Annual Shore/Bank Fishing Consumer Surplus (2008)
4a	Dare	Hatteras Island @ Avon	$2,727,408	$1,373,330
4a	Dare	Hatteras Island @ Salvo & Waves	$0	$1,315,573
4a	Dare	Hatteras Island @ Rodanthe	$0	$731,587
REGION 4a TOTALS=			$2,727,408	$3,420,490

Table XI-21. Shore and Pier Fishing – Region 4b

Coastal Region	County	Beach	Annual Pier/Bridge/Jetty Fishing Consumer Surplus (2008)	Annual Shore/Bank Fishing Consumer Surplus (2008)
4b	Dare	Pea Island	$0	$1,325,218
4b	Dare	Bodie Island	$391,463	$7,517,170
4b	Dare	Nags Head	$5,891,201	$659,920
4b	Dare	Kill Devil Hills	$0	$834,266
4b	Dare	Kitty Hawk	$5,076,187	$89,844
4b	Dare	Southern Shores	$0	$92,926
4b	Dare	Duck	$0	$41,366
4b	Dare	Sanderling	$0	$32,121
REGION 4b TOTALS=			$11,358,851	$10,592,830

Table XI-22. Shore and Pier Fishing – Region 4c

Coastal Region	County	Beach	Annual Pier/Bridge/Jetty Fishing Consumer Surplus (2008)	Annual Shore/Bank Fishing Consumer Surplus (2008)
4c	Currituck	Peters Quarter	$0	$184,620
4c	Currituck	Corolla	$0	$146,500
4c	Currituck	Currituck National Wildlife Refuge	$0	$0
4c	Currituck	Refuge to VA	$0	$60,542
REGION 4c TOTALS=			$0	$391,662

d) Marine Recreation Services

Marine recreational services are businesses that can be dependent on water access but are not direct beach recreation or fishing related. Some examples include ecotourism, canoe, kayak, and surf board rentals. Table XI-23 provides the economic values associated with marine recreation services on a per county basis for Region 4.

Table XI-23. Marine Recreation Services – Region 4a, 4b, and 4c (Dare and Currituck Counties)

Coastal Region	County	Number Businesses (2007)	Annual Direct Sales (2007)	Direct Employment (jobs) (2007)	Annual Total Impact Output/ Sales/ Business Activity (2007)	Total Impact Employment (jobs) (2007)	Annual Direct Sales (2008)	Annual Total Impact Output/ Sales/ Business Activity (2008)
4a, 4b, 4c	Dare, Currituck	45	$3,052,914	510	$6,412,503	533	$3,119,136	$6,551,600

e) Commercial Fishing

The employment value of fish landings and associated seafood processing industry economic values are presented in Table XI-24.

Table XI-24. Commercial Fishing – Region 4a, 4b, and 4c

Coastal Region	Waterway/Inlet	County	Estimated Direct Seafood Processing and Packing Output/Sales/Yr Supported by NC Seafood Landings 2007	Estimated Seafood Processing and Packing Jobs Supported by NC Seafood Landings 2007	Commercial Fishery Landings Direct Output/Sales (Dockside Value)/Yr 2007	Number of Commercial Fishing Jobs Supported 2007	Total Impacts on Business Activity/Sales 2008 (incl mult effects)	Total Jobs Supported 2008 (incl mult effects)
4a	AIWW	Dare	N/A	N/A	N/A		N/A	
4b	AIWW	Dare	N/A	N/A	N/A		N/A	
4b	Oregon Inlet	Dare	$82,666,940	405	$23,973,413	924	$139,150,200.84	1950
4c	AIWW	Currituck	N/A	N/A	N/A		N/A	
3b	Hatteras Inlet	Dare (Hatteras)	$16,006,335	78	$4,641,837		$26,942,872.05	
REGION 4 TOTALS=			$98,673,275	483	$28,615,250	924	$166,093,073	1,950

As a note, Hatteras Inlet values (Region 3b) were included in Table XI-24 since the analysis was done on a per county basis.

f) For Hire Fisheries

For hire fisheries include charter boats and head boats where people pay a fee to go fishing. Table XI-25 outlines the various spending, employment and economic impact of this industry segment.

Table XI-25. For Hire Fisheries – Region 4a, 4b, and 4c

Coastal Region	Waterway/Inlet	County	2008 For-Hire Fishery Passenger Direct Spending On Fishing Fees	2008 For-Hire Fishery Passenger Direct Spending On Other	2008 For-Hire Fishery Direct Captain & Crew Jobs Supported	2008 For-Hire Fishery Total Impact (incl mult effects) Business Activity	2008 For-Hire Fishery Total Impact (incl mult effects) Jobs Supported	2008 For-Hire Fishery Passenger Consumer Surplus
4a	AIWW	Dare						
4b	AIWW	Dare	$21,250,124	$50,528,854	315	$145,156,721	1809	$67,030,436
4b	Oregon Inlet	Dare						
4c	AIWW	Currituck	$719,369	$1,710,526	11	$4,913,911	61	$2,354,988
REGION 4 TOTALS=			$21,969,493	$52,239,380	326	$150,070,632	1,870	$69,385,424

g) Private Boating

The direct expenditures of private recreational boaters as well as the multiplier effects and associated jobs are present in Table XI-26 together with the consumer surplus value.

Table XI-26. Private Boating – Region 4a, 4b, and 4c

Coastal Region	Waterway/Inlet	County	2008 Direct Private Boater Spending per Yr	2008 Total Impact Business Activity/Sales per Yr	2008 Total Impact Jobs	2008 Consumer Surplus
4a	AIWW	Dare	$16,756,301	$29,203,839	535	$5,057,933
4b	AIWW	Dare				
4b	Oregon Inlet	Dare	No Data	No Data	N/A	No Data
4c	AIWW	Currituck	$129,927	$226,445	4	$39,219
REGION 4 TOTALS=			$16,886,228	$29,430,284	539	$5,097,152

h) Boat Building

The boat building industry employs people at various locations along the State's waterways. Boat builders rely on the maintenance of the waterways to create interest in the boating industry and subsequent sales of boats. Table XI-27 presents the direct sales and economic impact of the boat building industry.

Table XI-27. Boat Building – Region 4

Coastal Region	Waterway/Inlet	County	2008 Number of Firms	2008 Direct Sales	2008 Direct Employment	2008 Total Impact Output	2008 Total Impact Employment
4a	AIWW	Dare	No Data	No Data	No Data	No Data	No Data
4b	AIWW	Dare	23	$212,583,365	936	$279,146,662	1639
4b	Oregon Inlet	Dare	No Data	No Data	No Data	No Data	No Data
4c	AIWW	Currituck	1	No Data	No Data	No Data	No Data
REGION 4 TOTALS=			24	$212,583,365	936	$279,146,662	1639

i) Marinas

Coastal marinas support both private boating and for hire fishing charters. The data presented for marinas has some overlap with the private boating and for hire fishing data. Table XI-28 provides the economic marina data for Region 4.

Table XI-28. Marina Sales and Employment – Region 4

Coastal Region	Waterway/Inlet	County	2008 Number of Marinas	2008 Estimated Direct Marina Sales/Year	2008 Estimated Direct Marina Employment
4a	AIWW	Dare	9	$2,683,572	67
4b	AIWW	Dare	48	$14,312,386	357
4b	Oregon Inlet	Dare	No Data	No Data	No Data
4c	AIWW	Currituck	3	$894,524	22
REGION 4 TOTALS=			60	$17,890,483	446

B. Potential Beach and Inlet Management Strategies

Development of draft management strategies for coastal North Carolina must take into account a variety of measures including current management practices, associated costs, environmental considerations, economic valuation of beaches and inlets, and potential funding options. This section will discuss the current and potential strategies applicable to Region 4.

1. Historical Strategies

Historical strategies in North Carolina have included beach nourishment, coastal zone management practices *(i.e.*, setbacks, retreat), storm recovery *(i.e.*, dune reconstruction, planting, beach bulldozing, breach fill), dredging, sand bypassing, inlet relocation, and hard structures. Current methods applicable to Region 4 are presented in the following sections. Costs associated with each of the strategies have been updated to reflect 2008 values.

a) Beach Nourishment

A beach nourishment database has been compiled from several sources to provide a comprehensive summary of the States nourishment activities. Sources include the U.S. Army Corps of Engineers, Center for Developed Shorelines, Carteret County Beach Preservation Plan, Spencer Rogers of North Carolina Sea Grant, and Tom Jarrett with Coastal Planning & Engineering, Inc. The database extends over a time period from 1939 through 2007. There were no nourishment projects performed in Region 4c. A summary of the beach nourishment data for Region 4a and Region 4b is presented in Tables XI-29 and XI-30. The relative size of the projects listed in Tables XI-29 and XI-30 can be found in Figures XI-29 and XI-30. As can be seen from the figures, large projects have been performed in both subregions. In Region 4a, the large projects came from federal storm and erosion projects. Large projects in Region 4b are the result of federal navigation dredging projects. Beach nourishment project locations for each subregion of Region 4 can be seen in Figures XI-31 to XI-34. The complete beach nourishment database is in Appendix D following the report.

Table XI-29. Summary of Beach Nourishment Data – Region 4a

Location	First Year of Record	Number of Times Nourished	Total Amount Nourished (cy)	Average Unit Cost ($ / cy)	Cost per Project ($ / proj)
CAPE HATTERAS	1966	3	1,812,000	15.03	9,078,120
TOTAL REGION	**N/A**	**3**	**1,812,000**	**N/A**	**N/A**

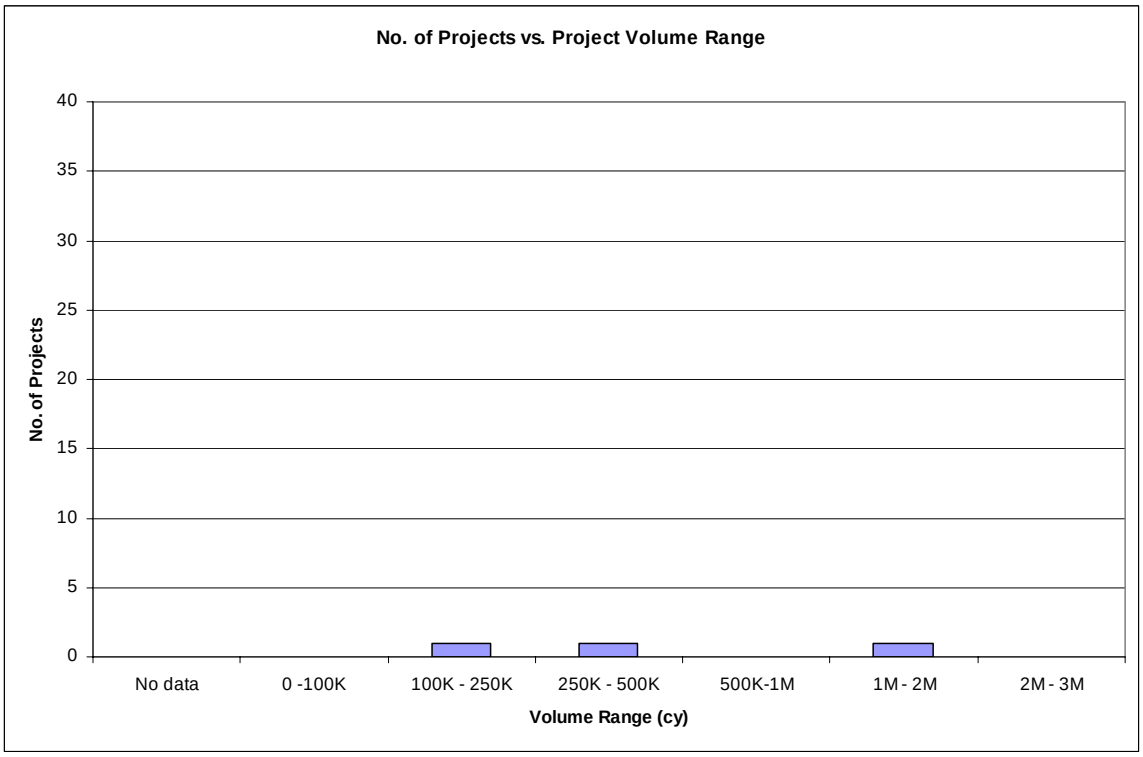

Figure XI-29. Number of Nourishment Projects – Region 4a by Project Size

Table XI-30. Summary of Beach Nourishment Data – Region 4b

Location	First Year of Record	Number of Times Nourished	Total Amount Nourished (cy)	Average Unit Cost ($ / cy)	Cost per Project ($ / proj)
NAGS HEAD	2001	2	278,000	5.28	139,000
OREGON INLET DISPOSAL ISLAND	1989	1	167,258	5.28	167,258
OREGON INLET OFFSHORE	1990	2	522,799	5.28	261,400
PEA ISLAND	1990	21	8,138,023	5.28	2,567,425
TOTAL REGION	**N/A**	**26**	**9,028,080**	**N/A**	**N/A**

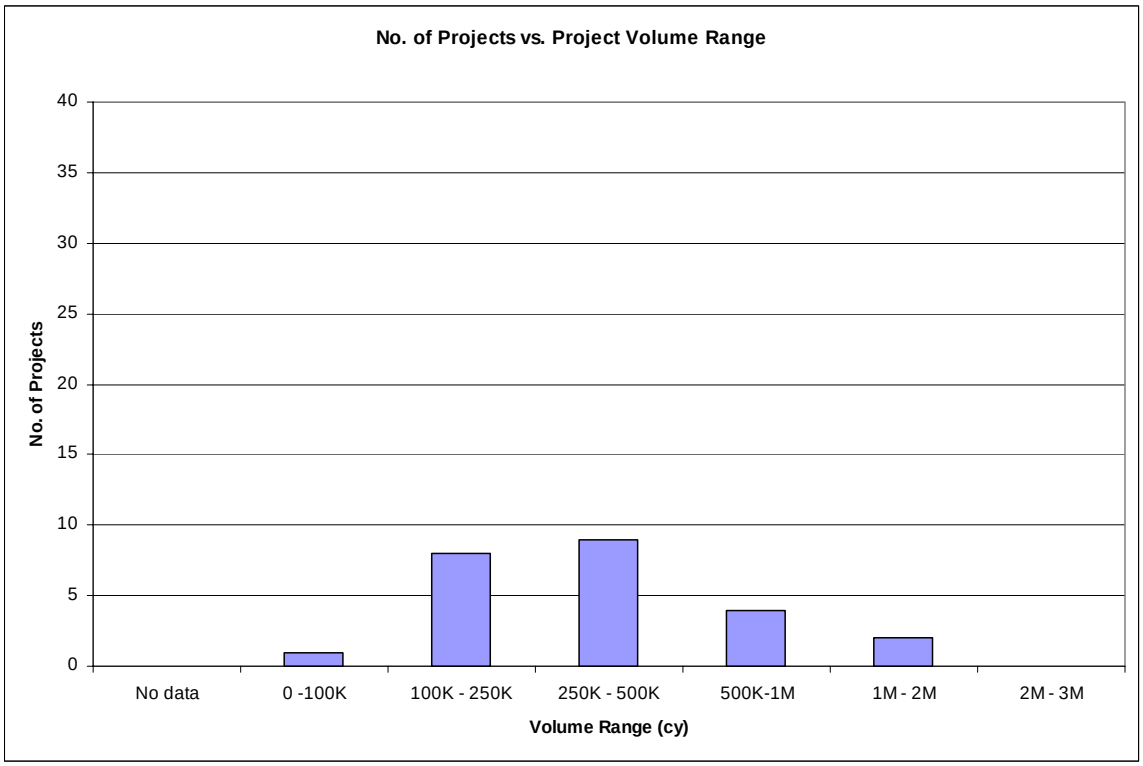

Figure XI-30. Number of Nourishment Projects – Region 4b by Project Size

Nourishment material comes from nearby inlets and channels. Table XI-31 shows the known historical borrow sources for each of the beaches in the subregions of Region 4.

Table XI-31. Historical Borrow Sources – Region 4 Beaches

Beach	Historical Borrow Sources
Hatteras Island	Hatteras Inlet
Pea Island	Oregon Inlet
Nags Head	Roanoke Sound, Shallowbag Bay

b) Coastal Zone Management

As mentioned previously, DCM has estimated long-term shoreline change rates based on the distance from the earliest digitized shoreline archived by the state (typically the 1940s) to the 1998 shoreline. Using these shoreline change rates, the CRC has established oceanfront setback factors which determine the minimum allowable distance between a structure and the first line of stable and vegetation during development. Currently, the minimum setback is 30 times the long-term average annual erosion rate (minimum of 60 feet) for all structures less than 5,000 square feet. Above 5,000 square feet, and every 5,000 square feet thereafter, the setback factor increases from 60 to 90 in increments of five. The maximum setback factor becomes 90 times the erosion rate for structures greater than or equal to 100,000 square feet.

In Region 4a, Hatteras Island at Buxton has a high average annual erosion rate of 10.0 feet per year. The erosion rate decreases moving north to Avon where it is 2.0 feet per year in southern Avon and then increases slightly to 4.0 feet per year in northern Avon. The erosion rate in the area of Hatteras Island at Salvo is 2.0 feet per year. It then increases to 14.0 feet per year at Rodanthe.

In Region 4b, Pea Island has an average annual erosion rate of 2.0 feet per year which increases to a maximum of 16.0 feet per year at Oregon Inlet. On the north side of Oregon Inlet, the rate increases from 2.0 feet per year at the inlet to 10.0 feet per year on Bodie Island. The rate then decreases again to between 2.0 and 3.0 feet per year between Nags Head and Sanderling.

c) Dredging

A dredging database has been compiled from 1975 to 2007 for projects performed or contracted by the USACE. Projects occurring prior to these dates were obtained from the North Carolina Historic Dredging Data book from the Wilmington district of the USACE. In a previous study by Moffatt & Nichol on shallow draft navigation (November 2005), a database was created of all shallow draft projects from 1975 through 2004. Deep draft projects and projects from 2005 to 2007 were added to this database. Dredge projects in Region 4 are limited to Region 4b (Oregon Inlet). Locations of dredge projects in Region 4b can be seen in Figure XI-36. The complete dredge database is available in Appendix E.

A summary of the dredge data from the database applicable to Region 4b is presented in Tables XI-32 to XI-34 for the whole dataset, the past 10 years, and the past five years. Figure XI-34 depicts the relative size of projects as well.

Table XI-32. Summary of Dredge Volume Data – Region 4b (1975-2007)

Location	Pipeline	Hopper	Sidecast	Currituck	Avg Volume
	(cy)	(cy)	(cy)	(cy)	(cy / YR)
OREGON INLET	994,923	8,898,146	17,356,729	604,977	1,114,191
OVERALL TOTAL (Potential Nourishment)	**994,923**	**8,898,146**	**17,356,729**	**604,977**	**1,114,191**
STUMPY POINT BAY	364,767	0	0	0	24,318
SHALLOWBAG BAY	12,425,438	0	0	0	414,181
OVERALL TOTAL	**13,785,128**	**8,898,146**	**17,356,729**	**604,977**	**1,552,690**

Table XI-33. Summary of Dredge Volume Data – Region 4b (1997-2007)

Location	Pipeline	Hopper	Sidecast	Currituck	Avg Volume
	(cy)	(cy)	(cy)	(cy)	(cy / YR)
OREGON INLET	0	2,268,441	4,430,371	222,020	692,083
OVERALL TOTAL (Potential Nourishment)	**0**	**2,268,441**	**4,430,371**	**222,020**	**692,083**
STUMPY POINT BAY	0	0	0	0	0
SHALLOWBAG BAY	3,962,377	0	0	0	396,238
OVERALL TOTAL	**3,962,377**	**2,268,441**	**4,430,371**	**222,020**	**1,088,321**

Table XI-34. Summary of Dredge Volume Data – Region 4b (2002-2007)

Location	Pipeline	Hopper	Sidecast	Currituck	Avg Volume
	(cy)	(cy)	(cy)	(cy)	(cy / YR)
OREGON INLET	0	988,331	2,705,682	222,020	783,207
OVERALL TOTAL (Potential Nourishment)	**0**	**988,331**	**2,705,682**	**222,020**	**783,207**
STUMPY POINT BAY	0	0	0	0	0
SHALLOWBAG BAY	3,171,712	0	0	0	634,342
OVERALL TOTAL	**3,171,712**	**988,331**	**2,705,682**	**222,020**	**1,417,549**

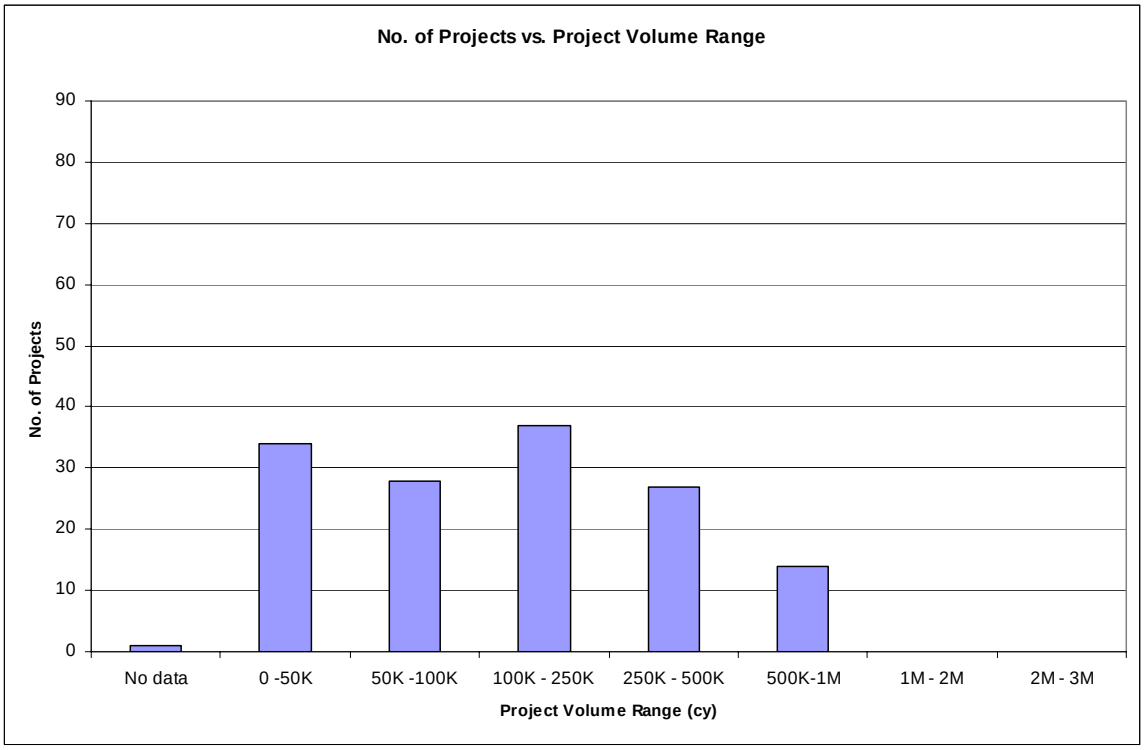

Figure XI-31. Number of Dredge Projects – Region 4b by Project Size

d) Structures

The state has prohibited the use of permanent erosion control structures since 1985, leaving the coast of North Carolina is relatively free of hardened engineered structures used to influence beach or inlet behavior. The ban on the use of permanent hardened structures has been both through the CRC's rules and more recently (2003) by law.

Some hardened structures which existed prior to 1985 include a groin field at Cape Hatteras near Buxton and a terminal groin at Oregon Inlet. Structures present in all three subregions of Region 4, including sandbags, are depicted in Figures XI-31 to XI-34.

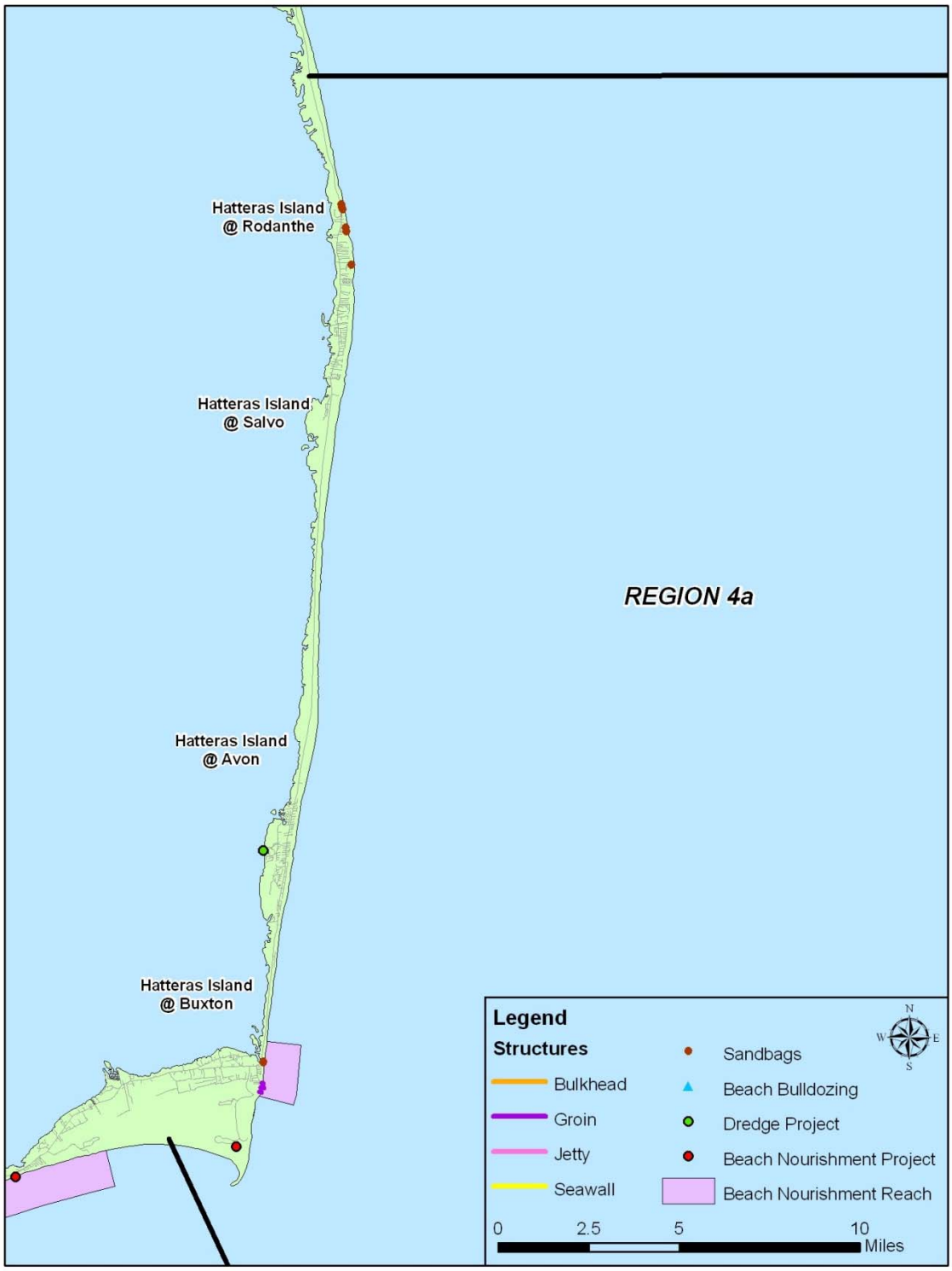

Figure XI-32. Historical Management Strategies for Region 4a

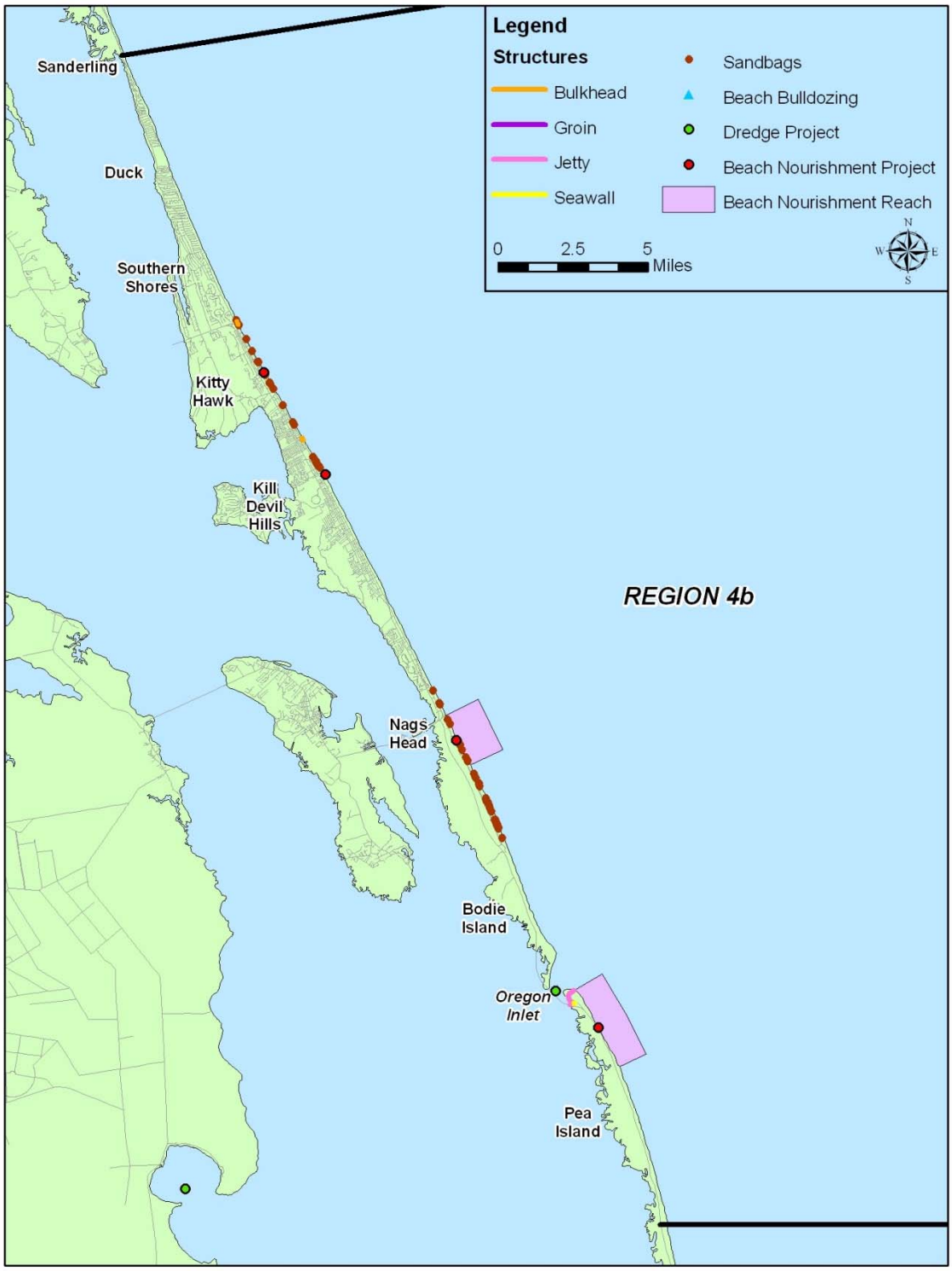

Figure XI-33. Historical Management Strategies for Region 4b

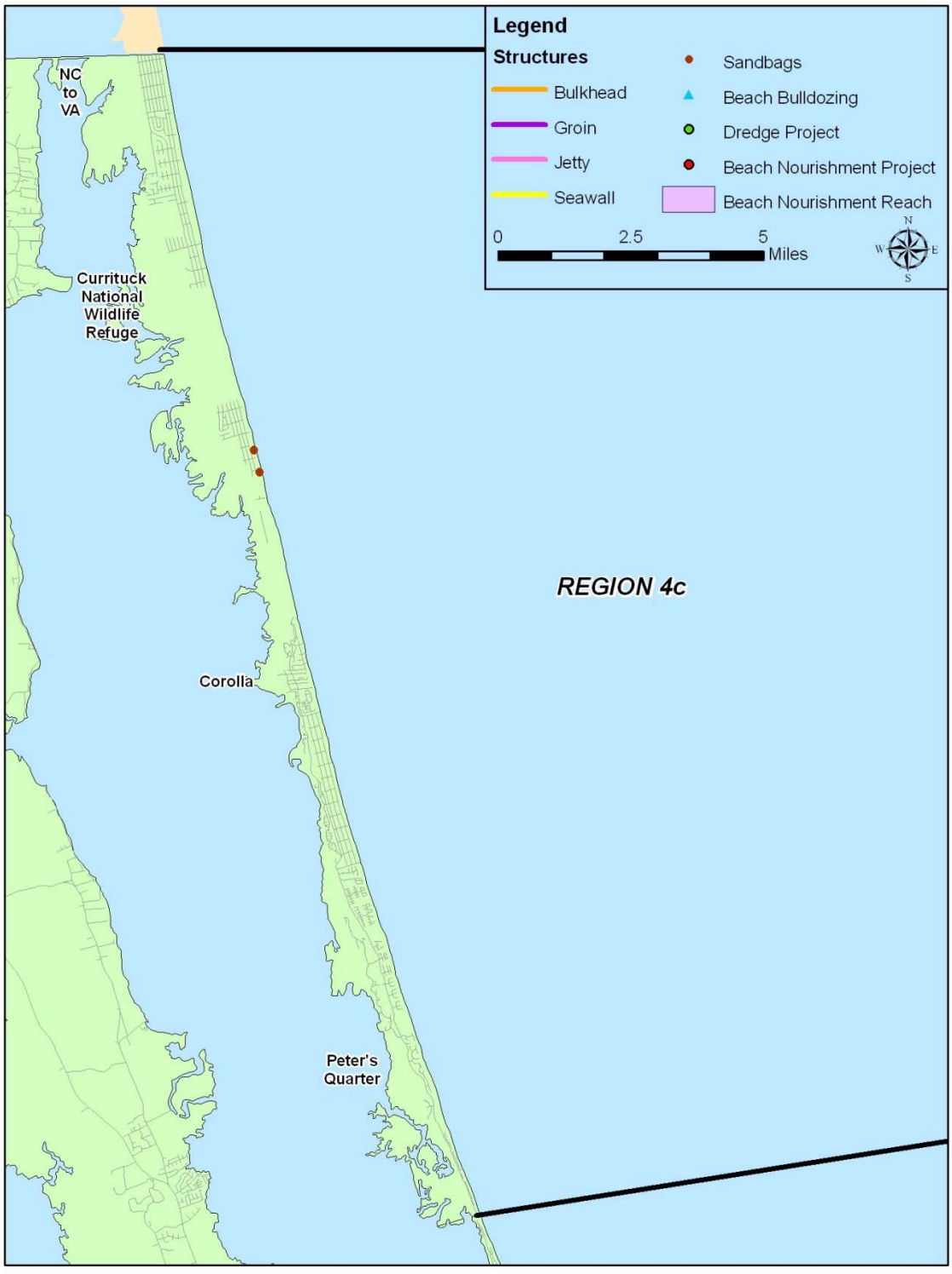

Figure XI-34. Historical Management Strategies for Region 4c

2. Potential Management Strategies

Current North Carolina policy relies on beach nourishment and dredging due to the prohibition on permanent erosion control structures. Continuation of these methods is expected with improvements in efficiency through the establishment of plans for location, frequency, quantity, and cost of nourishment projects on a cyclical basis. The adoption of a regional approach would also serve to ensure that all beach compatible sand from dredging projects is placed on the beach or back into the nearshore system. For example, coordinating dredging to maintain an inlet with beach nourishment or habitat creation would be an effective and efficient use of resources.

To begin this regionalized approach, sand sources within each region have been identified and tentatively assigned to various stretches of beach based on distance to the source. As discussed in Section VI covering strategy development, using sediment from offshore borrow areas or inlets is only cost effective up to a certain distance from the beach. Figures XI-35 to XI-37 show the locations and distances of the most likely sediment borrow areas for the various subregions of Region 4.

Tables XI-35 and XI-36 show the nearest inlet and offshore sources of sediment for the beaches in Region 4a as well as the most likely and reasonable source to be used for each beach based on distances and sediment quality.

Table XI-35. Nearest Sediment Sources – Region 4a Beaches

Location	Nearest Inlet Source		Nearest Offshore Source	
	Name	Distance (mi)	Name	Distance (mi)
Hatteras Island @ Buxton	N/A	N/A	No Name (NCGS)	3.1
Hatteras Island @ Avon	N/A	N/A	No Name (NCGS)	9.7
Hatteras Island @ Salvo	N/A	N/A	No Name (NCGS)	3.9
Hatteras Island @ Rodanthe	N/A	N/A	No Name (NCGS)	3.8

Table XI-36. Most Likely Sediment Sources – Region 4a Beaches

Location	Most Likely Source		Likely Dredge Type	Annual Need (CY)	Developed
	Name	Distance (mi)			
Hatteras Island @ Buxton	No Name (NCGS)	3.1	Pipeline/Hopper	237,174	N
Hatteras Island @ Avon	No Name (NCGS)	9.7	Pipeline/Hopper	105,989	Y
Hatteras Island @ Salvo	No Name (NCGS)	3.9	Pipeline/Hopper	20,438	Y
Hatteras Island @ Rodanthe	No Name (NCGS)	3.8	Pipeline/Hopper	228,629	Y

Tables XI-37 and XI-38 show the nearest inlet and offshore sources of sediment for the beaches in Region 4b as well as the most likely and reasonable source to be used for each beach based on distances and sediment quality.

Table XI-37. Nearest Sediment Sources – Region 4b Beaches

Location	Nearest Inlet Source		Nearest Offshore Source	
	Name	Distance (mi)	Name	Distance (mi)
Pea Island	Oregon Inlet	5.6	No Name (NCGS)	4.7
Bodie Island	Oregon Inlet	2.5	#3 (NCGS)	6.0
Nags Head	Oregon Inlet	10.6	S1 (NCGS)	3.4
Kill Devil Hills	Oregon Inlet	18.6	N2 (NCGS)	2.4
Kitty Hawk	Oregon Inlet	22.6	N1 (NCGS)	1.5
Southern Shores	Oregon Inlet	26.3	N1 (NCGS)	4.6
Duck	Oregon Inlet	30.0	N1 (NCGS)	8.2
Sanderling	Oregon Inlet	32.9	N1 (NCGS)	11.0

Table XI-38. Most Likely Sediment Sources – Region 4b Beaches

Location	Most Likely Source		Likely Dredge Type	Annual Need (CY)	Developed
	Name	Distance (mi)			
Pea Island	Oregon Inlet	5.6	Pipeline/Hopper	483,080	N
Bodie Island	Oregon Inlet	2.5	Pipeline/Hopper	153,650	N
Nags Head	S1 (NCGS)	3.4	Pipeline/Hopper	185,923	Y
Kill Devil Hills	N2 (NCGS)	2.4	Pipeline/Hopper	32,752	Y
Kitty Hawk	N1 (NCGS)	1.5	Pipeline/Hopper	55,833	Y
Southern Shores	N1 (NCGS)	4.6	Pipeline/Hopper	11,131	Y
Duck	N1 (NCGS)	8.2	Hopper	13,905	Y
Sanderling	N1 (NCGS)	11.0	Hopper	25,620	Y

Tables XI-39 and XI-40 show the nearest inlet and offshore sources of sediment for the beaches in Region 4c as well as the most likely and reasonable source to be used for each beach based on distances and sediment quality.

Table XI-39. Nearest Sediment Sources – Region 4c Beaches

Location	Nearest Inlet Source		Nearest Offshore Source	
	Name	Distance (mi)	Name	Distance (mi)
Peter's Quarter	N/A	N/A	No Name (USGS)	12.7
Corolla	N/A	N/A	No Name (USGS)	6.5
Currituck National Wildlife Refuge	N/A	N/A	No Name (USGS)	4.0
NC to VA	N/A	N/A	No Name (USGS)	7.3

Table XI-40. Most Likely Sediment Sources – Region 4c Beaches

Location	Most Likely Source		Likely Dredge Type	Annual Need (CY)	Developed
	Name	Distance (mi)			
Peter's Quarter	USGS Source	12.7	Hopper	28,982	N
Corolla	USGS Source	6.5	Pipeline/Hopper	88,828	Y
Currituck National Wildlife Refu	USGS Source	4	Pipeline/Hopper	184,657	Y
NC to VA	USGS Source	7.3	Pipeline/Hopper	84	N

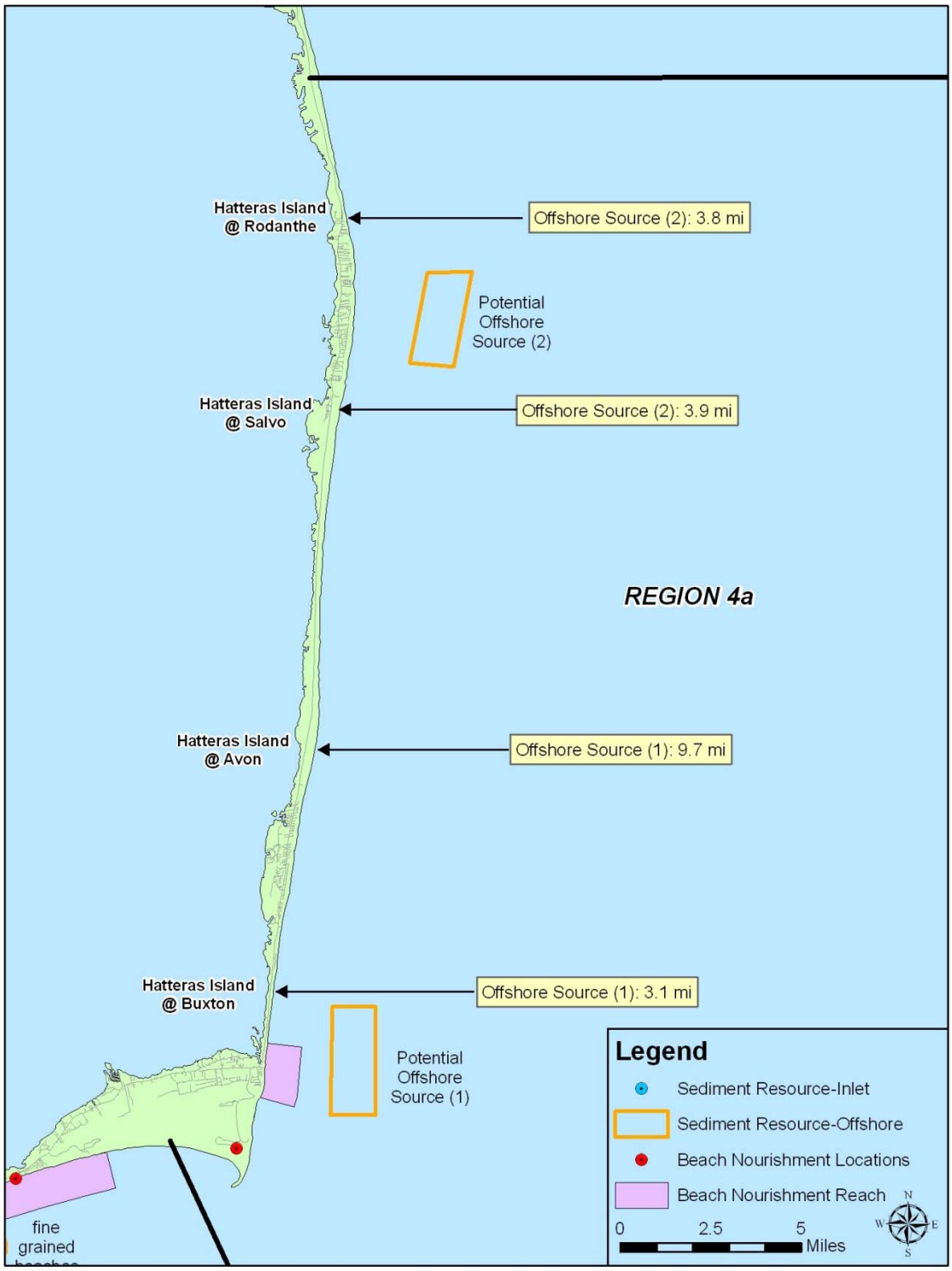

Figure XI-35. Potential Sediment Resources for Region 4a

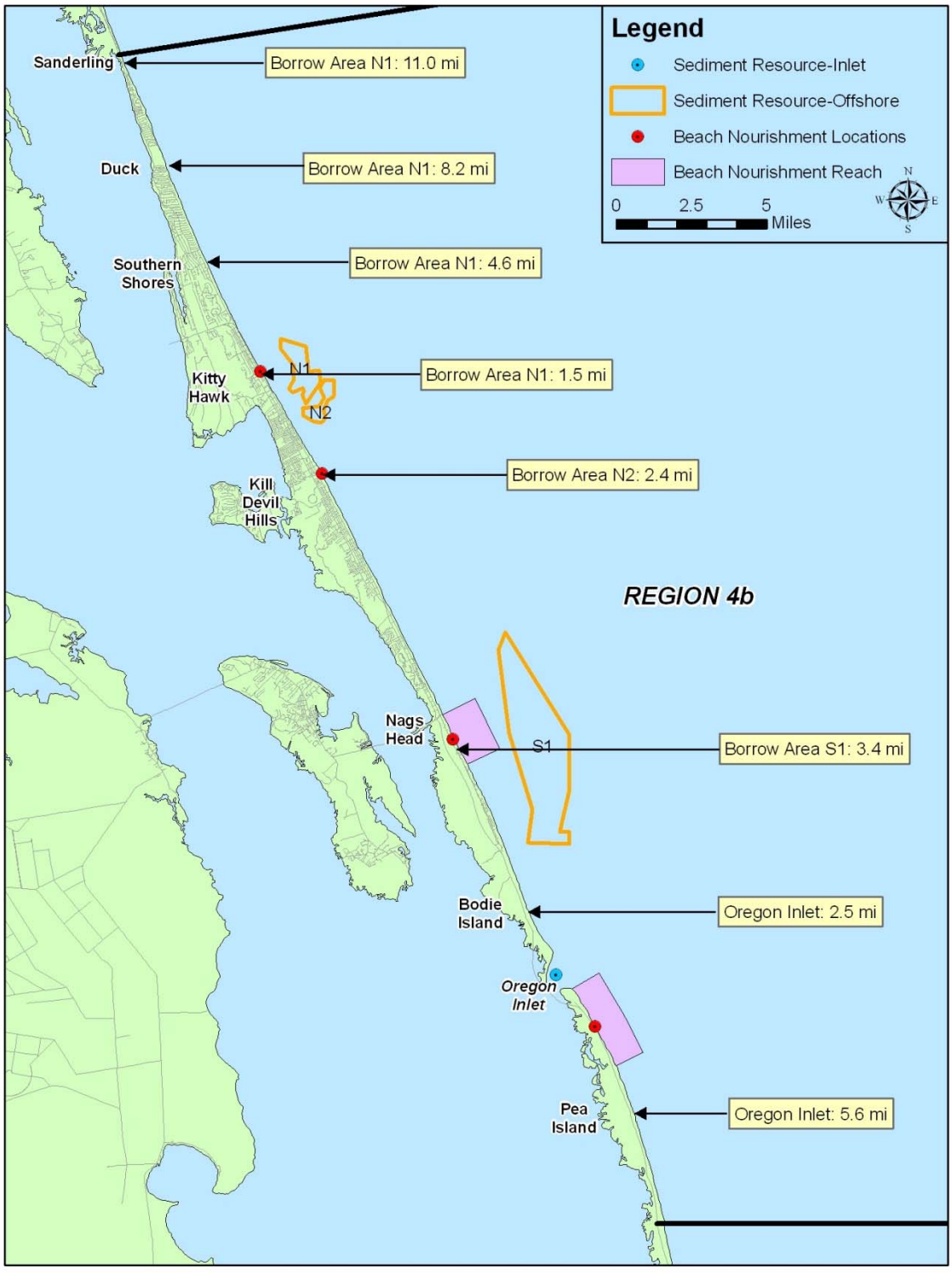

Figure XI-36. Potential Sediment Resources for Region 4b

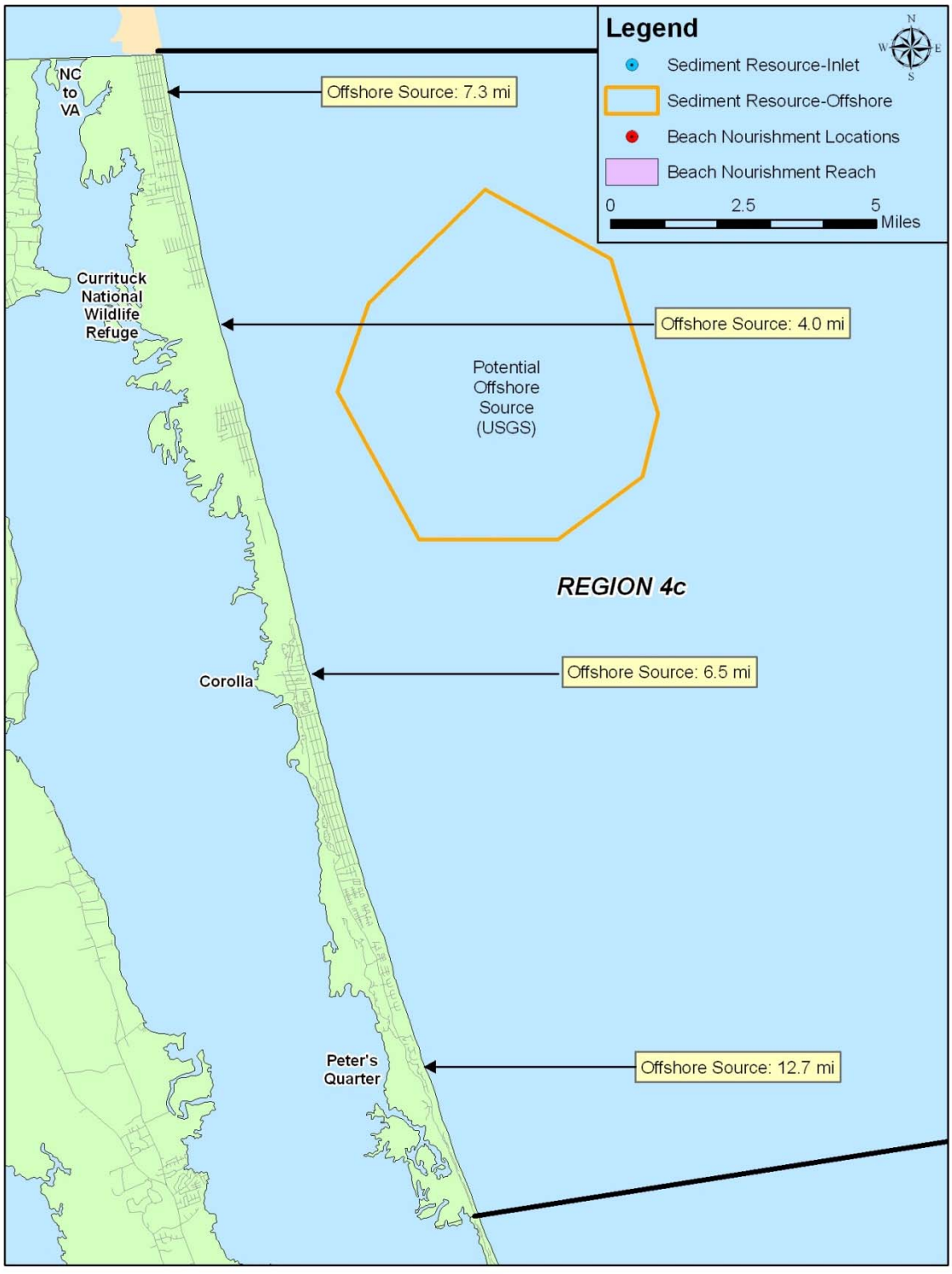

Figure XI-37. Potential Sediment Resources for Region 4c

C. Costs and Effectiveness of Strategies

1. Historical Costs

The beach nourishment and dredge databases were used to analyze historical costs for projects. Not all projects in the two databases contained cost information; therefore analysis was done in each case for the whole dataset, the past 10 years, and the past five years. Attention was paid to projects which were particularly costly or inexpensive so as not to bias the average costs that were calculated in the end. Costs associated with each of the strategies have been updated to reflect 2008 values.

a) Beach Nourishment

Tables XI-41 to XI-43 show the costs over various time periods for beach nourishment projects which have taken place in Region 4a. Region 4a as a whole has averaged approximately $665,000 per year in beach nourishment activities when the whole dataset was taken into account. However, only three projects have taken place in this area.

Table XI-41. Beach Nourishment Costs – Region 4a (Whole Dataset)

Location	First Year of Record	Number of Times Nourished	Average Unit Cost ($ / cy)	Avg Volume (cy/YR)	Avg Cost ($/YR)
CAPE HATTERAS	1966	3	15.03	44,195	664,390
TOTAL REGION	**N/A**	**3**	**N/A**	**44,195**	**664,390**

Table XI-42. Beach Nourishment Costs – Region 4a (1997-2007)

Location	Number of Times Nourished	Average Unit Cost ($ / cy)	Avg Volume (cy/YR)	Avg Cost ($/YR)
CAPE HATTERAS	0	0	0	0
TOTAL REGION	**0**	**N/A**	**0**	**0**

Table XI-43. Beach Nourishment Costs – Region 4a (2002-2007)

Location	Number of Times Nourished	Average Unit Cost ($ / cy)	Avg Volume (cy/YR)	Avg Cost ($/YR)
CAPE HATTERAS	0	0	0	0
TOTAL REGION	**0**	**N/A**	**0**	**0**

Tables XI-44 to XI-46 show the costs over various time periods for beach nourishment projects which have taken place in Region 4b. Region 4b as a whole has averaged approximately $3 million per year in beach nourishment activities when the whole dataset was taken into account. The costs over the past 10 years and the past five years were only slightly lower at $2.5 million and $2.8 million per year respectively.

Table XI-44. Beach Nourishment Costs – Region 4b (Whole Dataset)

Location	First Year of Record	Number of Times Nourished	Average Unit Cost ($ / cy)	Avg Volume (cy/YR)	Avg Cost ($/YR)
NAGS HEAD	2001	2	5.28	46,333	244,640
OREGON INLET DISPOSAL ISLAND	1989	1	5.28	11,151	58,875
OREGON INLET OFFSHORE	1990	2	5.28	30,753	162,375
PEA ISLAND	1990	21	5.28	478,707	2,527,830
TOTAL REGION	**N/A**	**26**	**N/A**	**553,944**	**2,925,080**

Table XI-45. Beach Nourishment Costs – Region 4b (1997-2007)

Location	Number of Times Nourished	Average Unit Cost ($ / cy)	Avg Volume (cy/YR)	Avg Cost ($/YR)
NAGS HEAD	2	5.28	27,800	146,784
OREGON INLET DISPOSAL ISLAND	0	0	0	0
OREGON INLET OFFSHORE	0	0	0	0
PEA ISLAND	11	5.04	469,689	2,365,593
TOTAL REGION	**13**	**N/A**	**489,689**	**2,471,193**

Table XI-46. Beach Nourishment Costs – Region 4b (2002-2007)

Location	Number of Times Nourished	Average Unit Cost ($ / cy)	Avg Volume (cy/YR)	Avg Cost ($/YR)
NAGS HEAD	1	5.28	27,800	146,784
OREGON INLET DISPOSAL ISLAND	0	0	0	0
OREGON INLET OFFSHORE	0	0	0	0
PEA ISLAND	5	5.11	531,726	2,717,771
TOTAL REGION	**6**	**N/A**	**551,726**	**2,823,371**

b) Dredging

Tables XI-47 to XI-49 show the costs over various time periods for dredging projects which have taken place in Region 4b. Region 4b as a whole has averaged approximately $9.5 million per year for dredging activities. Values were slightly lower over the last 10 years and last five years at $6.5 million per year and $8.7 million per year respectively.

Table XI-47. Dredging Costs – Region 4b (Whole Dataset)

Location	Pipeline	Hopper	Sidecast	Currituck	Avg Cost
	($)	($)	($)	($)	($ / YR)
OREGON INLET	6,462,789	57,739,071	91,946,748	3,398,031	6,381,866
OVERALL TOTAL (Potential Nourishment)	**6,462,789**	**57,739,071**	**91,946,748**	**3,398,031**	**6,381,866**
STUMPY POINT BAY	676,688	0	0	0	45,113
SHALLOWBAG BAY	92,826,208	0	0	0	3,094,207
OVERALL TOTAL	**99,965,685**	**57,739,071**	**91,946,748**	**3,398,031**	**9,521,185**

Table XI-48. Dredging Costs – Region 4b (1997-2007)

Location	Pipeline	Hopper	Sidecast	Currituck	Avg Cost
	($)	($)	($)	($)	($ / YR)
OREGON INLET	0	16,604,383	12,641,163	1,042,943	3,028,849
OVERALL TOTAL (Potential Nourishment)	**0**	**16,604,383**	**12,641,163**	**1,042,943**	**3,028,849**
STUMPY POINT BAY	0	0	0	0	0
SHALLOWBAG BAY	34,688,677	0	0	0	3,468,868
OVERALL TOTAL	**34,688,677**	**16,604,383**	**12,641,163**	**1,042,943**	**6,497,717**

Table XI-49. Dredging Costs – Region 4b (2002-2007)

Location	Pipeline	Hopper	Sidecast	Currituck	Avg Cost
	($)	($)	($)	($)	($ / YR)
OREGON INLET	0	4,487,023	7,529,811	1,042,943	2,611,955
OVERALL TOTAL (Potential Nourishment)	**0**	**4,487,023**	**7,529,811**	**1,042,943**	**2,611,955**
STUMPY POINT BAY	0	0	0	0	0
SHALLOWBAG BAY	30,525,761	0	0	0	6,105,152
OVERALL TOTAL	**30,525,761**	**4,487,023**	**7,529,811**	**1,042,943**	**8,717,108**

2. Potential Costs

In addition to historical quantity and cost data for beach nourishment and dredging projects, unit costs were developed for each stretch of beach for various nourishment scenarios encompassing different types of dredges and distances from sediment sources. For each stretch of beach in Region 4, the historical DCM erosion rates were used to estimate future volumetric needs. Unit costs were then applied to these needs to estimate potential costs for each region, on a yearly basis, which could then be summed to predict the cost for the entire coast. Tables XI-50 to XI-51 present the predicted annual costs for each subregion of Region 4. Section VI also contains a general discussion on the methodology employed for the development of potential strategies and costs for the entire State. Based on the findings outlined in Section VI, the predicted annual costs for the beach strategies below should be factored up by 1.3 to 1.7 (assumed to be 1.5 for this report) to account for cubic yards lost per foot of shoreline due to storm impacts cubic yards lost per foot of shoreline due to storm impacts. Since the shorelines in Region 4a comprise the National Seashore, the assumption is that they will not be nourished and are therefore not included in the overall nourishment needs assessment. Portions of the developed shoreline that have not received long-term beach fill placement (USACE or non-public funds) and are not included in the in a USACE beach fill study (Region 4c), have been excluded from this analysis as well. The volumes and costs in Tables XI-50 and XI-52 for sub-regions 4a and 4c are provided should these areas be considered as projects in the future. Note that the costs for the inlet maintenance (dredging) strategies are assumed to be equivalent to historical trends.

Table XI-50. Predicted Annual Costs – Region 4a Beaches

Location	Shoreline Length	Total Volume Needed	Total Volume Cost
	MI	CY	$
Cape Hatteras	4.75	153,202	1,829,231
Buxton	6.31	237,174	2,682,443
Avon	9.2	105,989	1,439,336
Salvo	7.15	20,438	239,330
Rodanthe	4.16	228,629	2,668,103
Pea Island	1.74	1,065	14,665
TOTAL DEVELOPED	**0**	**0***	**0***

*National Seashore or not included in USACE beach fill study

Table XI-51. Predicted Annual Costs – Region 4b Beaches

Location	Shoreline Length	Total Volume Needed	Total Volume Cost
	MI	CY	$
Nags Head	11.3	185,923	2,132,538
Kill Devil Hills	4.8	32,752	357,976
Kitty Hawk	3.5	55,833	578,984
TOTAL DEVELOPED	**19.6**	**274,508**	**3,069,498**

Table XI-52. Predicted Annual Costs – Region 4c Beaches

Location	Shoreline Length	Total Volume Needed	Total Volume Cost
	MI	CY	$
Peters Quarter	7.67	28,982	411,541
Corolla	6.09	88,828	1,130,784
Currituck NWR	6.52	184,657	2,171,570
NC to VA	2.52	84	1,086
Total	22.8	302,552	3,714,991
TOTAL DEVELOPED	**15.21**	**0***	**0***

*National Seashore or not included in USACE beach fill study

D. Data Gaps

During the data collection efforts several data gaps were identified that would greatly aid future updates to the BIMP and beach and inlet management projects. The following lists some of these key data gaps in Region 4 by general topic:

Geology

- Inlet bathymetry – Detailed inlet surveys covering morphological features of Oregon Inlet were not located. (Navigation channel surveys for Oregon Inlet can be located through USACE website – http://www.saw.usace.army.mil/nav/)
- Sand source investigations – Offshore sand sources in Region 4c should be further investigated.

Physical Processes

- Sediment budget – The sediment budget at Oregon Inlet should be updated from the one published by the USACE in 1980. No other areas of Region 4 have sediment budgets.

Monitoring

- Improved beach profile monitoring plans – Region 4a and Region 4c do not have any regularly monitored stretches of shoreline.