A Comprehensive Site Profile for the North Carolina National Estuarine Research Reserve

August 2008

Respectfully compiled and submitted by the staff of the
North Carolina National Estuarine Research Reserve

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LIST OF ABBREVIATIONS

NCNERR	North Carolina National Estuarine Research Reserve
CZMA	Coastal Zone Management Act
NERRS	National Estuarine Research Reserve System
NOAA	National Oceanic and Atmospheric Administration
NERRA	National Estuarine Research Reserve Association
SWMP	System Wide Monitoring Plan
GRF	Graduate Research Fellowship
KEEP	K-12 Estuarine Education Program
NCCR	North Carolina Coastal Reserve Program
DCM	North Carolina Division of Coastal Management
UNCW	University of North Carolina at Wilmington
GIS	Geographic Information System
SAV	Submerged Aquatic Vegetation

Chapter 1: Introduction to the North Carolina National Estuarine Research Reserve

1.1: Document Overview

This document is meant to serve as an introductory overview of the properties that make up the North Carolina National Estuarine Research Reserve (NCNERR) and the research and monitoring activities that occur at the Reserves. This material includes: the location of the Reserve properties; the environmental setting of the properties (geologic, biologic and ecologic); the habitat types contained in the properties; the research that has occurred within the properties; Reserve partners and partnership opportunities; and the important coastal management issues and/or threats facing each property. This document is meant to be readable by scientists and non-scientists alike. Knowledge gaps identified in this document will serve as a guide to direct future Reserve activities.

1.2: National Estuarine Research Reserve System

A: Establishment

The National Estuarine Research Reserve System (NERRS) was established by section 315 of the Coastal Zone Management Act (CZMA) of 1972 as amended. This landmark legislation was designed to encourage the participation and cooperation of state, local, regional, and federal agencies and governments having programs affecting the coastal zone of the United States. Through the Act, Congress declared that is was national policy to:

(1) to preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations;

(2) to encourage and assist the states to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone, giving full consideration to ecological, cultural, historic, and esthetic values as well as the needs for compatible economic development, which programs should at least provide for--

(A) the protection of natural resources, including wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitat, within the coastal zone,

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

(C) the management of coastal development to improve, safeguard, and restore the quality of coastal waters, and to protect natural resources and existing uses of those waters,

(D) priority consideration being given to coastal-dependent uses and orderly processes for siting major facilities related to national defense, energy, fisheries development, recreation, ports and transportation, and the location, to the maximum extent practicable, of new commercial and industrial developments in or adjacent to areas where such development already exists,

(E) public access to the coasts for recreation purposes,

(F) assistance in the redevelopment of deteriorating urban waterfronts and ports, and sensitive preservation and restoration of historic, cultural, and esthetic coastal features,

(G) the coordination and simplification of procedures in order to ensure expedited governmental decisionmaking for the management of coastal resources,

(H) continued consultation and coordination with, and the giving of adequate consideration to the views of, affected Federal agencies,

(I) the giving of timely and effective notification of, and opportunities for public and local government participation in, coastal management decisionmaking,

(J) assistance to support comprehensive planning, conservation, and management for living marine resources, including planning for the siting of pollution control and aquaculture facilities within the coastal zone, and improved coordination between State and Federal coastal zone management agencies and State and wildlife agencies, and

(K) the study and development, in any case in which the Secretary considers it to be appropriate, of plans for addressing the adverse effects upon the coastal zone of land subsidence and of sea level rise; and

(3) to encourage the preparation of special area management plans which provide for increased specificity in protecting significant natural resources, reasonable coastal-dependent economic growth, improved protection of life and property in hazardous areas, including those areas likely to be affected by land subsidence, sea level rise, or fluctuating water levels of the Great Lakes, and improved predictability in governmental decisionmaking;

(4) to encourage the participation and cooperation of the public, state and local governments, and interstate and other regional agencies, as well as of the Federal agencies having programs affecting the coastal zone, in carrying out the purposes of this title;

(5) to encourage coordination and cooperation with and among the appropriate Federal, State, and local agencies, and international organizations where appropriate, in collection, analysis, synthesis, and dissemination of coastal management information, research results, and technical assistance, to support State and Federal regulation of land use practices affecting the coastal and ocean resources of the United States; and

(6) to respond to changing circumstances affecting the coastal environment and coastal resource management by encouraging States to consider such issues as ocean uses potentially affecting the coastal zone.

Section 304 of the CZMA defines the coastal zone

(1) The term "coastal zone" means the coastal waters (including the lands therein and thereunder) and the adjacent shorelands (including the waters therein and thereunder), strongly influenced by each other and in proximity to the shorelines of the several coastal states, and includes islands, transitional and intertidal areas, salt marshes, wetlands, and beaches. The zone extends, in Great Lakes waters, to the international boundary between the United States and Canada and, in other areas, seaward to the outer limit of State title and ownership under the Submerged Lands Act (43 U.S.C. 1301 et seq.), the Act of March 2, 1917 (48 U.S.C. 749), the Covenant to Establish a Commonwealth of the Northern Mariana Islands in Political Union with the United States of America, as approved by the Act of March 24, 1976 (48 U.S.C. 1681 note), or section 1 of the Act of November 20, 1963 (48 U.S.C. 1705), as applicable. The zone extends inland from the shorelines only to the extent necessary to control shorelands, the uses of which have a direct and significant impact on the coastal waters, and to control those geographical areas which are likely to be affected by or vulnerable to sea level rise. Excluded from the coastal zone are lands the use of which is by law subject solely to the discretion of or which is held in trust by the Federal Government, its officers or agents.

Since its inception in 1972, the NERRS has grown to a network of 27 Reserves in 23 different states (Figure 1.1).

Figure 1.1: Map of the National Estuarine Research Reserve System.
Courtesy of NOAA.

The Reserves are operated as a partnership between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states and territories. NOAA provides funding, national guidance and technical assistance, while the states provide matching funds, personnel, and managerial oversight. Each Reserve is managed on a daily basis by a lead state agency, university or non-profit organization, with input from local partners and citizens. This partnership program between NOAA and the coastal states and territories protects more than one million acres of estuarine land and water, which provide essential habitat for wildlife; offer educational opportunities for students, teachers and the public; and serve as living research laboratories for scientists.

The NERRs are managed based on the following vision and mission statements (from NERRS Strategic Plan 2005-2010 included as Appendix 1):

> Vision: "Healthy estuaries and coastal watersheds where coastal communities and ecosystems thrive."

Mission: "To practice and promote coastal and estuarine stewardship through innovative research and education, using a system of protected areas."

The strategic plan identifies three goals to facilitate these overarching principles. They are:

1. Strengthen the protection and management of representative estuarine ecosystems to advance estuarine conservation, research and education.

2. Increase the use of Reserve science and sites to address priority coastal management issues.

3. Enhance peoples' ability and willingness to make informed decisions and take responsible actions that affect coastal communities and ecosystems.

The mission, vision and goals of the NERRS serve to support a nationwide effort to enhance coastal zone management, advance estuarine research, and educate current and future generations of coastal stewards (Riley 2006).

B: NERRS Organization

The NERRS is operationally administered under NOAA's National Ocean Service by the Estuarine Reserves Division. The Estuarine Reserves Division provides national coordination and ensures the NERRS are fully integrated with other NOAA programs and activities. The NERRS is also supported by a non-profit organization, the National Estuarine Research Reserve Association (NERRA). NERRA was created in 1987 to promote and advance the NERRS. NERRA is dedicated to the protection, understanding, and science-based management of our nation's estuaries—the valuable areas where the river meets the sea. NERRA works with Congress, NOAA, and public and private partners to increase support for research, monitoring, education, and stewardship within the NERRS. NERRA also provides public education and outreach to improve awareness and understanding of the importance of estuaries and coasts. The NERRS is organized into research, education and stewardship sectors. These sectors all have unique goals and programs as outlined below but work together in a collaborative manner that supports the NERRS mission.

C: NERRS National and System-wide Initiatives

a: Research

The research sector is focused on enhancing scientific understanding of all aspects of estuarine function. This includes, but is not limited to, eutrophication and water quality changes, coastal ocean processes, climate change, invasive species, the interaction between land and water, and flora and fauna ecological interactions. This is accomplished through three core programs conducted by all 27 NERRS: 1) site research; 2) the system wide monitoring program (SWMP); and 3) the Graduate Research Fellowship (GRF).

Site research refers to the high quality hypothesis driven research projects that are conducted within the Reserves. These projects are conducted both by Reserve staff and outside researchers. These projects provide the baseline science needed to develop sound management decisions and quality education material. Support for these projects is provided by a variety of funding sources including NOAA, the National Science Foundation, the Environmental Protection Agency, Sea Grant, and many more. These projects also provide countless partnership opportunities as visiting scientists and NERRS staff work together on research projects. One partnership and funding agency in particular, NOAA's Cooperative Institute for Coastal and Estuarine Environmental Technology, highly encourages proposals that demonstrate collaboration with the NERRS and that are conducted within NERRS' boundaries.

SWMP refers to the monitoring program conducted at all 27 NERRS across the country. SWMP consists of three phases. Phase 1 is to monitor abiotic parameters. These include atmospheric conditions and water quality. Atmospheric conditions are monitored using Campbell Scientific (815 West 1800 North Logan, Utah 84321-1784) weather stations, and water quality conditions are monitored using Yellow Springs Instruments (1700/1725 Brannum Lane Yellow Springs, OH 45387-1107) 6600 series and newer in-situ sondes. Parameters measured include air temperature, relative humidity, barometric pressure, rainfall, wind speed, and wind direction for atmospheric conditions and dissolved oxygen, pH, temperature, conductivity and turbidity for water quality conditions. Phase 2 is to monitor biological parameters. These include submerged aquatic vegetation (SAV) and emergent marsh spatial and temporal distribution, nekton biodiversity, and benthic infauna biodiversity. Phase 3 is to map watershed and land habitat types, and quantify changes through time. SWMP phase 1 was initiated in the early 1990s with two sampling stations per reserve and has grown to include four water quality locations and one atmospheric sampling site within each Reserve. Sampling for nutrients (NO_2^-/NO_3^-, NH_4^+, and PO_4^{-3}), and Chlorophyll *a* was added to SWMP in 2002. In the mid 2000s SWMP phase 1 was incorporated as part of the national backbone of the Integrated Ocean Observing System. The Integrated Ocean Observing System is a multi-agency network of federal and regional coastal and ocean observing systems designed to expand our ability to collect, deliver, and use ocean information. This upgrade provided satellite transmitters for each Reserve for one water quality and one atmospheric sampling location. The transmitters allow the data to be viewed in near real time by anyone with a network connection. This rapid data transmission allows the data to be used daily by many user groups to plan activities. All of the SWMP data is stored, quality checked and assured and maintained by NOAA's Centralized Data Management Office. Data managed by the CDMO can be accesses online at http://cdmo.baruch.sc.edu. Phase 2 and 3 of SWMP are being implemented as funding allows. Most Reserves are conducted biological monitoring associated with phase 2 of SWMP. Phase 3 is the most recent aspect of SWMP to be implemented. Pilot projects were conducted at 5 Reserves to develop and finalize the methods to make up a national protocol for SWMP phase 3. NCNERR was one of these pilot Reserves. The results from our phase 3 pilot project are included in this document. The rest of the Reserves will be conducting phase 3 over the next 5 years.

Created in 1997, the GRF is a program designed to encourage and enable talented young scientists to contribute to the knowledge base, provide the science to support coastal decision-making and train future coastal scientists and policy-makers. The GRF program provides funding to master's and Ph-D. level graduate students for projects conducted within the NERRS. The projects are based on the Reserves' local needs, the Reserve system's national priorities and the students' interest. GRF awards have supported students from over 78 different academic institutions. The GRF is one of the largest graduate programs supported by NOAA, and thanks to the federal state partnership structure of the NERRS is uniquely capable at translating new research findings into better coastal policy.

b: Education

National Estuarine Research Reserves are federally designated to "enhance public awareness and understanding of estuarine areas, and provide suitable opportunities for public education and interpretation." The NERRS is one of only four programs within NOAA in which education is federally mandated, and the Reserve system provides a wide range of educational programs to fulfill that mandate. The education sector targets professionals who make decisions about coastal resources on a regular basis, such as planners, conservation council members, resource managers and community leaders, through its Coastal Training Program. In addition to targeting coastal decision makers, the education sector also offer hands-on field classes for K-12 students and support for teachers through professional development programs in marine education. The national K-12 Estuarine Education Program (KEEP) provides teachers and students with the knowledge, appreciation and skills to act as stewards of estuarine environments. Students and teachers can also learn about estuaries by actively participating in the EstuaryLive Program, which is an interactive, web-based, field trip available nationwide. One final goal of the education sector is to utilize SWMP data and other research results in the creation of educational products. This collaboration between the education and research sector ensures rapid and successful knowledge transfer.

The Coastal Training Program ensures that community members and coastal decision makers have up-to-date, science-based information that they need to make informed decisions about coastal resources. Coastal Training Programs offered by Reserves focus on issues such as coastal habitat conservation and restoration, biodiversity, water quality and sustainable resource management. Programs target a range of audiences, including land-use planners, elected officials, regulators, land developers, community groups, environmental non-profits and coastal businesses and are developed in a variety of formats ranging from seminars, hands-on skill training, participatory workshops, lectures, and technology demonstrations. These training programs provide a range of opportunities for professionals to network across disciplines, and develop new collaborative relationships to solve complex environmental problems. Through this program, National Estuarine Research Reserves can ensure that coastal decision-makers have the knowledge and tools they need to address critical resource management issues of concern to local communities.

The NERRS K-12 Estuarine Education Program was developed to increase ocean literacy in students and teachers. KEEP not only teaches students about coastal and estuarine processes, but it also develops and strengthens data literacy, critical thinking, team building, and problem solving skills in students of all ages. The program has four basic goals: 1) increase ocean literacy of K-12 students and teachers about coastal and estuarine ecosystems; 2) increase the number of teachers trained to teach students about estuarine and coastal ecosystems; 3) promote a better understanding of the National Estuarine Research Reserve System; and 4) encourage responsible stewardship of estuarine, natural and cultural resources. KEEP uses a multifaceted approach that is designed to provide teachers with appropriate estuarine-based lessons plans as well as hands-on field experiences for teachers and students within the Reserves.

The NERRS is currently developing new curriculum for K-12 students and teachers as part of its K-12 Estuarine Education Program. This curriculum, called Estuaries 101, will teach key principles and concepts of estuarine ecology and illustrate how estuaries relate to other human and ecological systems, while teaching to national and state science standards. Place-based activities using the NERRS' SWMP and the NOAA Chesapeake Bay Interpretive Buoy System will allow teachers to bring relevant, real-time scientific data into the classroom. In 2008, NERRS educators will train and support teachers on the use of KEEP products, such as the 9–12 grade portion of Estuaries 101 and the powerful web-interface that manipulates data for teaching various estuarine concepts. To compliment existing professional teacher development programs, Teachers on the Estuary (TOTE) programs will be offered nationwide which emphasize ocean literacy principles and concepts and introduces teachers to the Estuaries 101 curriculum and the web-interface. The training will provide meaningful use of regional estuarine data in the classroom. Another national education initiative that is part of KEEP is the EstuaryLive Program. EstuaryLive broadcasts are free, live Internet field trips held in estuaries around the country. These broadcasts are designed for classroom use and can be viewed by anyone. Participating Reserves host different sessions on a variety of estuarine topics.

c: Stewardship

The stewardship sector's primary focus is to ensure that the properties and resources of the Reserve remain in a natural state that supports education and research activities. At the same time, the Stewardship sector must manage the impacts of traditional uses of the resources and provide for public access to the sites. Stewardship activities include the preservation of critical habitats and protection of native plant and animal species, particularly listed (endangered, threatened and rare) species. Although there are no system-wide stewardship programs at this time due to the widely varying issues and management needs at each Reserve, some common system-wide themes include restoration activities, invasive species management, visitor use impacts, and trash and debris control.

The stewardship sector works very closely with the education and research sectors, jointly conducting projects such as biological monitoring, habitat mapping, and public field trips. Stewardship staff also partners extensively with state and federal agencies, academic institutions, and non-governmental organizations, helping to promote the Reserve's programs and leveraging additional resources that contribute to the accomplishment of its mandates.

1.3: North Carolina National Estuarine Research Reserve

A: North Carolina Environmental Setting

North Carolina lies between 33.5° and 37° north latitude and between 75° and 84.5° west longitude midway along the U.S. Eastern seaboard (Figure 1.2). The total area of the State is 52,712 square miles (136,524 km^2), of which 49,142 square miles (127,278 km^2) are land and 3,570 squares miles (9,246 km^2) are water. North Carolina contains there distinct land regions, the Mountain Region, the Piedmont Region, and the Coastal Plain and two unique biogeographical provinces, the Virginian and Carolinian (Figure 1.2).

The land and water areas of the Coastal Plain comprise nearly half the area of the State. North Carolina contains the nation's second largest estuarine/lagoonal system (Paerl et al. 2001), covering more than 2.3 million acres (9,308 km^2). The soils of the coastal plain consist of soft sediment, with little or no underlying hard rock near the surface.

There are no distinct wet and dry seasons in North Carolina. Summer precipitation is typically highest, with July being the wettest month. Summer rainfall is also the most variable, occurring mostly in connection with showers and thunderstorms. Autumn is the driest season, with November the driest month. Precipitation during winter and spring occurs mostly in connection with migratory low pressure storms, which appear with greater regularity and in a more even distribution than summer showers. Snow and sleet are rare on the coastal plain. The average relative humidity does not vary greatly from season to season but is generally the highest in winter and lowest in spring. The lowest relative humidities are found over the southern Piedmont, where the year around average is about 65 percent. The highest are along the immediate coast, averaging around 75 percent.

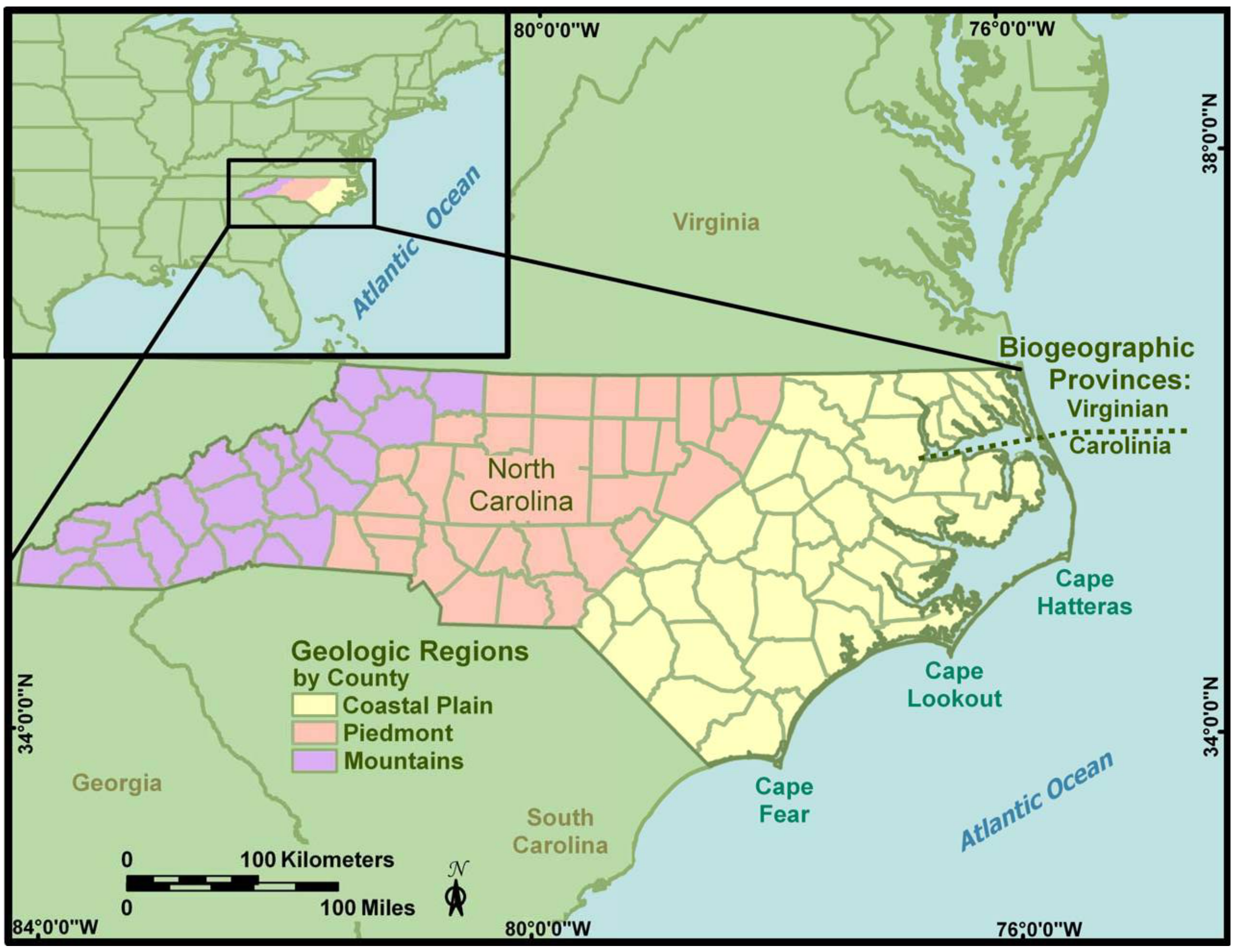


Figure 1.2: North Carolina geological regions and biogeographical provinces.

Temperature in North Carolina is extremely variable and depends on many factors such as altitude and the influence of Oceanic currents. In all seasons, the average temperature varies more than 20 °F (~11 °C) from the eastern most coastal areas compared to the highest mountain peaks. Temperatures as low as 0 °F (~ -18 °C) are rare outside the mountains. Winter temperatures in the eastern portions of the coastal plain are modified by the Atlantic Ocean, which raises the average winter temperature and decreases the average day-to-night range compared to more inland areas. The rise in average daily temperatures is greater in May than in any other month. The average daily maximum reading in midsummer is below 90 °F (~32 °C) for most localities. Morning temperatures along the coast are usually 10 to 15 °F (~5.5 to 8 °C) lower than the afternoon maximum. Autumn is the season of most rapidly changing temperature, the daily downward trend being greater than the corresponding rise in spring. The drop-off is greatest during October, and continues at a rapid pace in November, so that average daily temperatures by the end of that month are within about five degrees of the lowest point of the year (all climate data obtained from the State Climate Office of North Carolina).

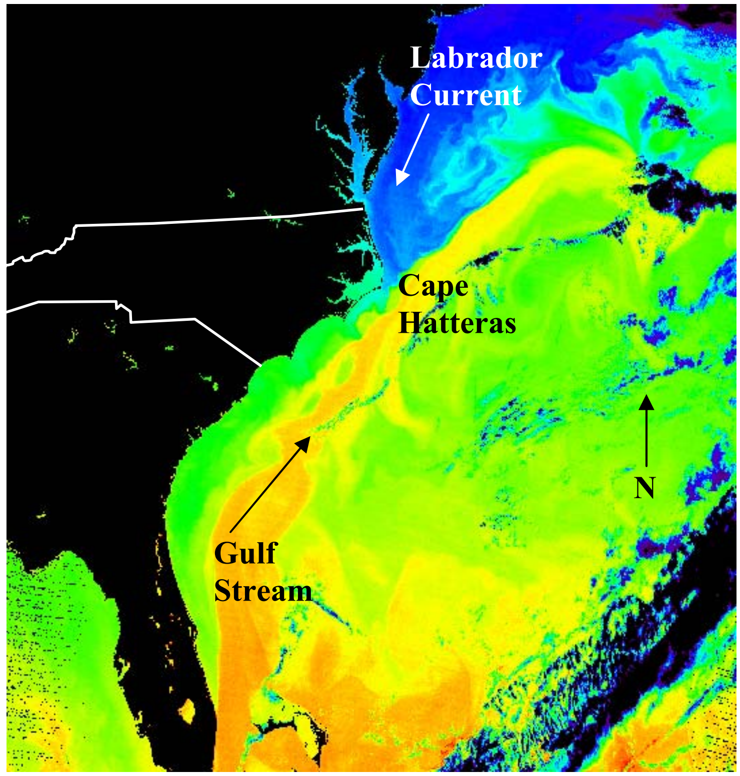


Figure 1.3: Ocean currents off of the coast of North Carolina. The warm waters of the Gulf Stream show up in yellow and move northward, the cold waters of the Labrador Current show up in blue and move southward.

The immediate coastal regions of North Carolina are influenced greatly by the prevailing ocean currents. Two ocean currents, the Gulf Stream and the Labrador Current, converge off of Cape Hatteras (Figure 1.3). The Gulf Stream provides a warming effect to the southern coastal areas, and the Labrador Current provides a cooling effect for the northern coastal section. In the immediate coastal areas this can cause several degrees of difference between the northern (cooler) and southern (warmer) coastal areas. The convergence of these currents provides a rich biological region off the North Carolina coast where species from both the Carolinian (warmer) and Virginian (cooler) biogeographic provinces coexist. The mixing of the warm and cold waters also helps fuel oceanic storms off the coast of North Carolina. North Carolina is subject to two types of oceanic storms, tropical storm/hurricanes and Nor'Easters. Both types of storms can produce large amounts of precipitation and gale force winds. Tropical storms and hurricanes are warm cored systems with a closed circulation containing a defined eye wall structure. These storms are a yearly threat from July through November, and feed off the warm waters of the Gulf Stream. Nor'Easters typically form during the winter months when a cold cored low pressure system, associated with a front, moves up the coast and intensifies due gradients in atmospheric conditions along the Labrador/Gulf Stream interface. Both storm types can influence areas well inland from the coast.

There are also large differences in tidal range, salinity, and size of the back barrier sounds in North Carolina moving from the Virginia to South Carolina border (Figure 1.4). In the northern region, the back barrier sounds (Currituck and Albemarle) are medium sized and due to their distance to ocean inlets effectively cut off from the coastal ocean. As a result, diurnal tides in the Currituck and Albemarle Sounds are essentially non-existent. Water level changes in the sounds are primarily attributable to wind driven forcing. Salinity values in these sounds are much lower

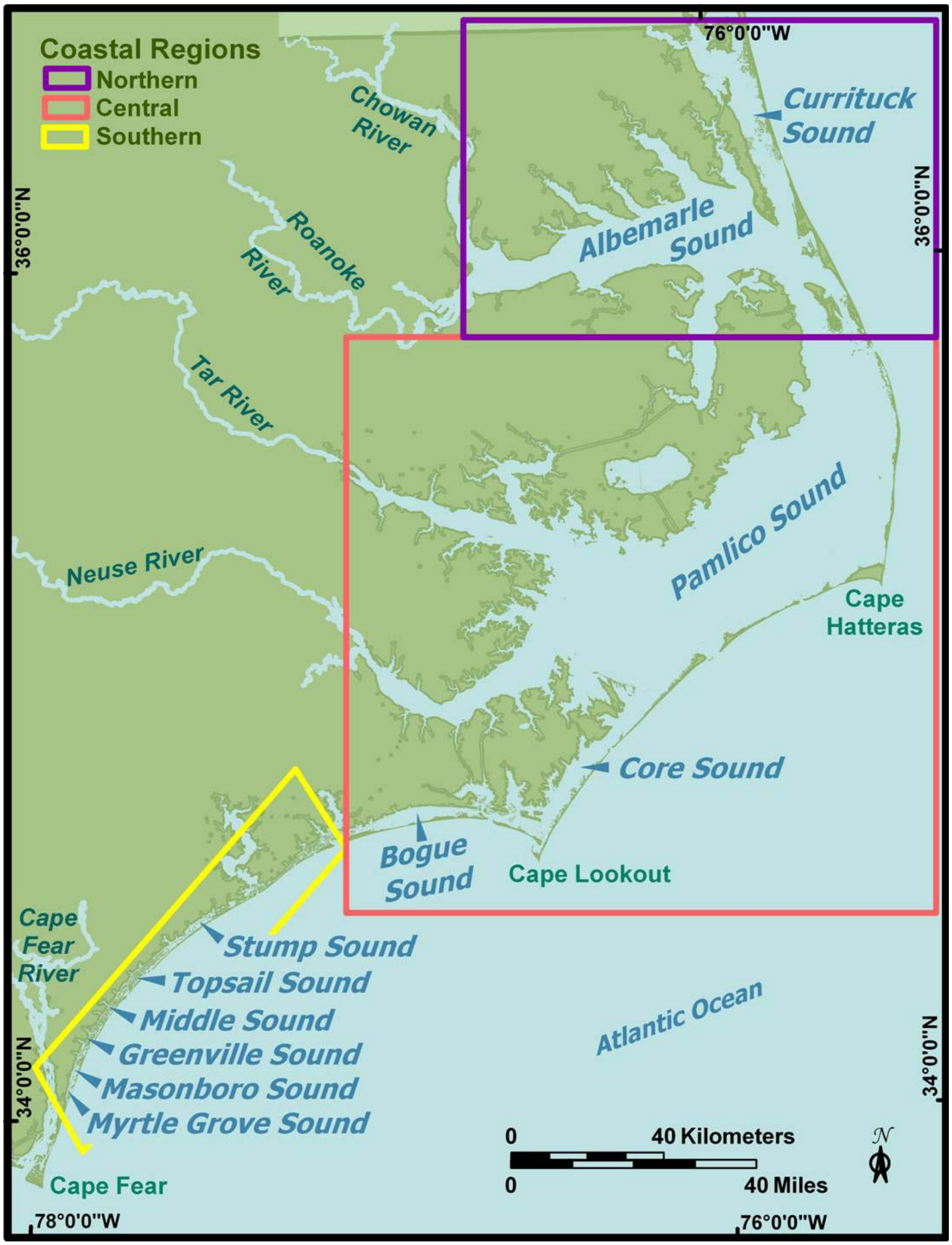


Figure 1.4: North Carolina coastal regions and back barrier sounds.

(2-7 ppt) compared to those values from the coastal ocean (35 ppt) and those from the sounds farther south. In the central region of North Carolina, there is one extremely large sound

(Pamlico) and several small ones to the south (Core, Back, and Bogue). Tidal range in these sounds ranges from 0.5 to 3.5 ft (~0.2 – 1 m) depending on distance from an ocean inlet. Salinity in the sounds in the central region also varies based on distance from an ocean inlet. Typical values range between 15-25 ppt. The sounds in the southern region of North Carolina (Stump, Topsail, Middle, Greenville, Masonboro, and Myrtle Groove) are smaller than those to the north as the barrier islands tend to be much closer to the mainland than those northward. Consequently, their tidal range is closer to the coastal ocean values which in this region range from 3 to 6 ft (~0.9 – 1.8 m). Salinity in these sounds is also much closer to coastal ocean values ranging from 25-35 ppt. These differences in North Carolina's back barrier sounds make the estuarine environments in the northern, central and southern parts of the state very different.

B: NCNERR Site Selection and Designation

The diverse range of habitats in North Carolina noted above made it an ideal location for a NERR. In order to capture the full breadth of this diversity, a multi-component NERR was planned for the State. This approach allowed all the estuarine ecosystems present in the State to be represented and protected. In 1982 the state of North Carolina received is first federal award toward the establishment of the NCNERR. Four properties were selected to become components of NCNERR. Three of the components were designated in 1985 (Currituck Banks, Rachel Carson, and Zeke's Island) and Masonboro Island was designated six years later in 1991. These properties comprise over 10,000 acres of land and water habitat and protect land from the northern, central and southern parts of North Carolina. (Figures 1.4 and 1.5).

C: State Coastal Reserve Program

The four properties that make up the NCNERR are part of the larger North Carolina Coastal Reserve Program (NCCR). The NCCR contains 10 Reserves (including the 4 NERR locations), representing more than 32,000 acres (Figure 1.5). The State Reserves from north to south are: Kitty Hawk Woods; the Emily and Richardson Pryer Buckridge Coastal Reserve; Buxton Woods; Permuda Island; Bald Head Woods; and Bird Island (Figure 1.5). The NCCR was authorized by the N.C. General Assembly in 1989 to protect unique coastal locations. The overarching goal for the NCCR is preservation of the land for long-term research, education, stewardship and public use. The environmental setting and research activities at the State Coastal Reserves are beyond the scope of this document. Information regarding the state Reserves can be found on the NCCR website (www.nccoastalreserve.net).

D: Administrative Structure

The lead state partner for NCNERR is the North Carolina Department of Environment and Natural Resources - Division of Coastal Management (DCM). The DCM implements the State's Coastal Area Management Act, the Dredge and Fill Law and the federal CZMA of 1972 in the 20 coastal N.C. counties (Figure 1.5), using rules and policies of the N.C. Coastal Resources Commission. The main office for DCM is located in Morehead City, N.C. (Figure 1.5). The core staff positions for NCNERR are DCM employees. This arrangement is ideal as it allows for rapid incorporation of new information learned from research into coastal policy.

The NCCR, of which the NCNERR is a part, is administered out of four offices (Figure 1.5). The main office is located in the central region in Beaufort, North Carolina. This office is a joint facility shared between the NCCR and the NOAA Center for Coastal Fisheries and Habitat Research. This arrangement allows NCNERR and the NOAA lab to share meeting rooms, shop facilities and greatly enhances collaboration. This office permanently houses the Reserve: manager; research coordinator; education coordinator; coastal training program coordinator; and an education specialist. Space also exists for additional staff members when needed and to accommodate program growth. The University of North Carolina at Wilmington (UNCW) is subcontracted by DCM to administer 7 full-time permanent contract positions for Reserve staff and to provide office facilities and logistical support for four NCCR staff in the southern region. This office is located in New Hanover County at the Center for Marine Science.

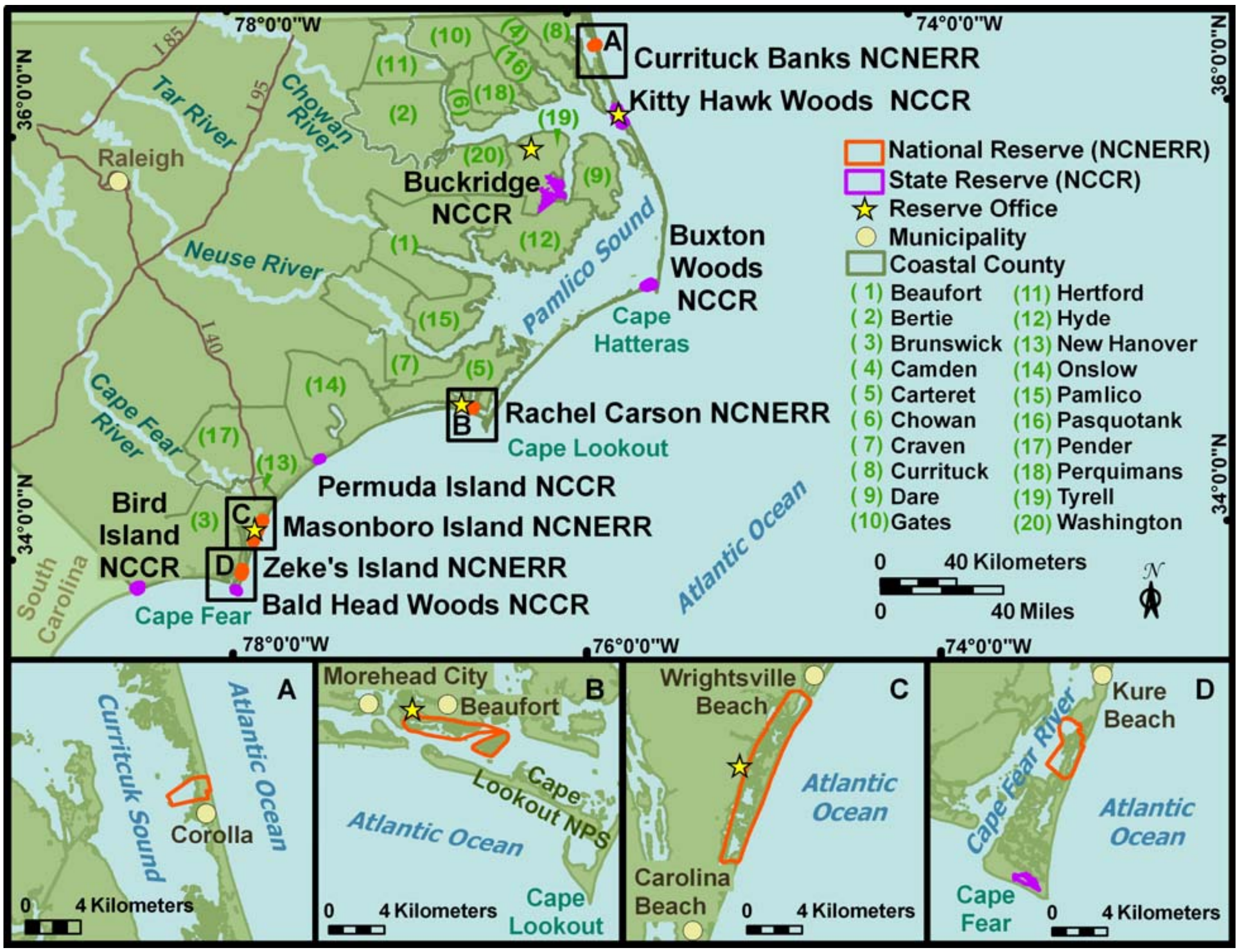


Figure 1.5: North Carolina national (red) and state (purple) reserve component locations. Coastal area counties are outlined in grey and identified by numbers. Reserve offices are denoted by the yellow star.

This arrangement is codified by a long-standing memorandum of understanding between UNCW and DCM. The staff located in this office includes the stewardship coordinator, two research assistants and a geographic information system (GIS) specialist. A northern region office is located in Dare County, at the Kitty Hawk Woods NCCR in Kitty Hawk, N.C. This office houses the northern sites manager and a contractual part-time research assistant. The final

NCCR office is located in Tyrell County in Columbia, N.C. This office houses the Buckridge Coastal Reserve manager. This office is co-located with the North Carolina Division of Marine Fisheries. This arrangement like the office in Beaufort, N.C. provides many advantages for shared resources and collaboration.

E: Administrative Partners

Several other institutions support the day to day activities of NCNERR. The Duke Marine Lab has provided, at greatly reduced cost boat dockage at our Rachel Carson Reserve component. The University of North Carolina – Institute of Marine Sciences provides laboratory space for NCNERR staff in the Morehead City/Beaufort area. The University of North Carolina – Coastal Studies Institute provides laboratory space for Reserve staff in the Kitty Hawk/Currituck area. The North Carolina Wildlife Resources Commission – Outer Banks Center for Wildlife Education in Corolla, N.C. provides NCNERR staff with boat resources for activities on Currituck Sound. The Carolina Estuarine Reserve Foundation is a local non-profit organization that supports NCNERR. The foundation provides NCNERR with community outreach, and financial support. This is not meant to be an exhaustive list of NCNERR's partners; however, without the assistance of these organizations, the capabilities of NCNERR would be greatly diminished.

F: Components of NCNERR

The smallest, most northern and only Reserve component located in the Virginian biogeographic province is the 960 acre (3.9 km^2) Currituck Banks. Currituck Banks is located in Currituck County, just north of the village of Corolla. This component comprises pristine maritime forest, beach intertidal areas, dune swales, and brackish marshes. Water areas within the Currituck Banks component contain vast beds of freshwater submerged aquatic vegetation. These SAV beds provide important habitat for fish and feeding areas for migratory waterfowl.

The central portion of the State is represented by the 2,625 acre (10.6 km^2) Rachel Carson component. This component is located in Carteret County between the town of Beaufort, Harkers Island and the Cape Lookout National Seashore. The Rachel Carson component contains large areas of salt-marsh and vast stretches of sand and mud flats. Upland areas are vegetated by scrub-shrub species and small trees. Water areas within the Rachel Carson component contain shellfish beds and three species of seagrass.

The Rachel Carson component is named after famed naturalist Rachel Carson, a pioneer female scientist who is considered the founding force behind today's environmental movement. In July of 1938, Rachel Carson came to Beaufort, N.C. and worked for the U.S. Fisheries Station. She fell in love with the area and researched the marshes and islands that now make up the Reserve, and especially enjoyed observing shorebirds and discovering the marsh pools, ponds and sand flats (Lear 1997). Rachel Carson's first book, *Under the Sea Wind*, was published in 1941 and opened with a long evocation of a May evening at Beaufort's Town Marsh and Bird Shoal (see Figure 3.1) (Cecelski 2000). During the Reserve dedication it was named in honor of Rachel Carson and her many accomplishments.

The largest Reserve component is the 5,047 acre (20.4 km^2) Masonboro Island. This component consists of a pristine undeveloped barrier island. It is situated in New Hanover County between the towns of Wrightsville Beach and Carolina Beach. Masonboro Island contains beach intertidal areas, dune swales and an extensive backside salt marsh-tidal creek system. Shellfish beds consisting of predominately oysters and clams are found within the tidal creeks of Masonboro Island.

The southern most Reserve component is the 1,165 acre (4.7 km^2) Zeke's Island component. Zeke's Island encompasses land in both Brunswick and New Hanover counties, and is located just south of Kure Beach. Zeke's Island contains beach intertidal areas, dune swales, large areas of salt marsh, upland forested areas, sand and mud flats.

1.4: NCNERR Strategic Plan

The NCNERR is administered according to its management plan. The management plan is updated every five years to reflect national, state, and local needs. This process allows NCNERR to be adaptive to new and changing priorities. The current national priorities are highlighted in the NERRS strategic plan (Appendix 1). The NCNERR management plan can be found at the NCCR website (www.nccoastalreserve.net). The overarching goal of the NCCR/NCNERR is to provide high quality research and locations for research, education outreach activities aimed at disseminating the results of the high quality research, and land stewardship to ensure the properties remain natural and unchanged for future generations. The mission and vision statements for NCNERR are:

Vision: Healthy estuaries and coastal watersheds where ecological communities thrive and the human community benefits in North Carolina.

Mission: To promote informed management and stewardship of North Carolina's estuarine and coastal habitats through research, education and example.

To help foster these vision and mission statements, a set of goals have been developed. These include:

1. Humans understand the natural systems, their connections to them, and the benefits derived from them.
2. Applicable research informs coastal policy.
3. NCNERR habitats and land use of associated watersheds are characterized and connections understood.
4. Habitat is protected and the public has directed access to NCNERR components.
5. NCNERR operations, infrastructure, and stature are improved.

The vision, mission, and goals were developed by NCNERR staff through strategic planning and logic model tools with the assistance of the NOAA Coastal Services Center. The goals integrate NCNERR programs, obscuring the lines between education, research, and stewardship.

1.5: SWMP History and Current Framework

The multi-component design of NCNERR is supported by three offices. During the formative years of NCNERR, there was not enough staff to conduct research, education and stewardship activities at all components. This problem was alleviated by concentrating sector activities to certain Reserve components. The research staff and activities were concentrated in Wilmington, N.C. at the Masonboro and Zeke's Island components. The education activities and staff were concentrated in the Beaufort, N.C. area at the Rachel Carson component. The stewardship staff and activities were located in Kitty Hawk, N.C. and primarily worked at the Currituck Banks component. Through staff reorganization, creation of new positions and new partnerships the NCNERR is working toward a new philosophy where activities of all sectors are conducted at all locations.

SWMP was initiated during the period of time when most of the NCNERRs research activities were concentrated in the southern region. Thus the Masonboro and Zeke's Island components are where the SWMP phase 1 monitoring stations are located. There are two water quality monitoring stations at both Masonboro and Zeke's Islands for a total of four. There is also a weather station located at Masonboro Island. In order to maintain the long-term dataset (>10 years), it is not desirable to relocate these sampling stations. But, given the varied estuarine climates within North Carolina noted in section 1.3, it is desirable to have water quality sampling at Rachel Carson and Currituck as well. Efforts have been made to accommodate this when funding and staff resources made it possible. These sampling stations are maintained exactly like those at Masonboro and Zeke's Islands but are not considered official SWMP stations. These stations at Rachel Carson and Currituck are considered SWMP-like. The data from the SWMP-like stations is of the same quality as that from the SWMP stations. Data from the SWMP and SWMP-like stations are located in each Reserve component's respective chapter.

1.6: Research Strategic Plan

The research sector of NCNERR is managed according to all the above listed management documents and overall vision statements. Complimenting these documents is the NERRS Research and Monitoring Plan (2006-2011) (Appendix 2). This document provides four goals that direct the system-wide research and monitoring efforts.

Goal 1: Biological, chemical, physical, and ecological conditions of Reserves are characterized and monitored to describe reference conditions and to quantify change.

Goal 2: Scientists conduct research at Reserves that is relevant to coastal management need and increase basic understanding of estuarine processes.

Goal 3: Scientists, educators, and coastal managers have access to NERRS datasets, science products and results.

Goal 4: The scientific, coastal management and education communities, as well as the general public, use data, products, tools, and techniques generated at the NERRS.

These national plans and documents provide excellent direction to the research sector of NCNERR. However, to be truly useful, the research sector at NCNERR must deal with issues important to local managers, scientist and citizens. To determine what the locally important research issues were, a needs assessment was conducted by our coastal training program. The needs assessment was directed at local: scientist; resource managers; and citizens. The results from this endeavor showed that research was needed in the following areas: 1) Water quality degradation and eutrophication; 2) Shellfish bed degradation and sustainability; and 3) Habitat mapping and change. Additional sector guidance was derived from the research and monitoring needs identified by the North Carolina Coastal Habitat Protection Plan (Appendix 3). All of these national, regional and local needs were considered when developing the strategic goals for the research sector of NCNERR. Four strategic goals were devised.

Strategic Goal 1) Conduct all phases of the SWMP at all four NCNERR components.

Strategic Goal 2) Conduct and/or facilitate research activities at all four components with priority given to projects dealing with eutrophication, fecal contamination, and habitat change.

Strategic Goal 3) Seek partnerships to further the capabilities and credibility of the research sector

Strategic Goal 4) Disseminate through outreach activities and publications the findings of research activities conducted in NCNERR.

1.7: North Carolina Coastal Issues

There are several overarching issues faced by North Carolina's entire coast that will be pervasive themes throughout this document as they affect all components of NCNERR. These include both anthropogenic as well as natural processes. Issues affecting all NCNERR components include eutrophication, altered land use and cover, invasive species, tropical and coastal storm impacts, and sea level rise. While these are not all the issues affecting the Reserve components, they are ones that impact all of them.

Eutrophication leads to excessive phytoplankton production. This can lead to a multitude of water quality problems including hypoxia, decreased light penetration, altered community composition, loss of SAV, and decreased fish and shellfish populations. Recovery from eutrophication can take long periods of time even if the causes of the eutrophication are immediately halted (Nixon 1995; Paerl et al. 1998; Mallin et al. 2000a; Niemi et al. 2004).

Altered land use and cover is a critical issue because how the land is used and the type of cover on it has large impacts on its ability to sequester nutrients and pollution rather than convey them to surface waters. Natural land covers such as forest and marsh have large buffering capacities. They tend to trap nutrients and sediment prior to them entering surface waters.

Developed land tends to have very little capacity to absorb nutrients and pollution. This is because developed land has increased impervious surfaces such as roofs, roads, and parking lots. These surfaces do not let water infiltrate the ground and high percentages of impervious surfaces have been correlated with degraded water and sediment quality (Mallin et al. 2000b; Holland et al. 2004). Consequently runoff from these surfaces usually picks up whatever contaminants and nutrients are on them and rapidly moves these materials to surface waters (Mallin et al. 2000b; Mallin et al. 2001).

Invasive species is one of the largest and most pervasive problems facing not only North Carolina but also the nation. An invasive species is one that begins to live and reproduce in an area where it is not naturally found. This is problematic because when this happens there usually are not any of the species natural predators to keep it in check, and the new species tends to utilize resources at the expense of an existing native one. Invasive species are usually very opportunistic and hard to get rid of once established.

North Carolina's geography makes it prone to strikes by tropical and coastal storm systems. These storms can bring tremendous amounts of wind and rain to the State. They also are capable of causing large amounts of coastal erosion and can even cause new inlets to form. All of these issues are important for the properties of NCNERR.

Sea level rise is occurring along the North Carolina coast. Estimates for the amount of rise range from 0.3 to 3.0 mm/year, with most values between 1-2 mm/year (Gormitz 1995). Reliability of these estimates has been questioned due to the data quality, physical processes and a high level of spatial variability (Gormitz 1995). Some estimates range for sea level rise to be approximately 48-50 cm higher by 2100 (Gormitz 1995; Gregory and Oerlemans 1998). There are many potential problems associated an increase in sea level. The most important in terms of the Reserve properties is loss of marsh habitat. If the sea level rise is faster than the ability of the marsh to accrete sediment and build itself up, then the marshes will be swamped (Moorhead and Brinson 1995). This would cause not only a decrease in the size of all the Reserve properties, but also would represent a loss of vital nursery habitat.

Chapter 2: Currituck Banks Component

2.1: Environmental Setting

The Currituck Banks component of the NCNERR is the northern most component and is the only component located in the Virginian biogeographic province. Currituck Banks encompasses 960 acres (3.9 km^2) in the northeastern corner of North Carolina's northern Outer Banks in Currituck County. The Reserve property lies just north of the unincorporated village of Corolla, ten miles (16 km) south of the Virginia border. The nearest population center is Elizabeth City, N.C., approximately 20 miles (~32 km) to the west. The Nature Conservancy and U.S. Fish and Wildlife Service properties bound Currituck Banks to the north, the Atlantic Ocean to the east, the Currituck Sound to the west, and private subdivisions to the south (Figure 2.1). Currituck Banks is located in the Pasquotank River Basin. Currituck Banks was one of the three original NERRS components dedicated by NOAA and DCM in 1985 (Masonboro was added in 1991). Currituck Banks is accessible by foot traffic and boat however no boat ramp or dock is available within the Reserve boundaries. The northern portion of the Reserve is accessible only by four-wheel drive along the beach corridor after N.C. 12 terminates at the beach access ramp. Two walking trails exist at the southern portion of the property just off state route N.C. 12 where public parking and handicap access is available.

2.2: Historical Uses

A: Native American Usage

Before the European settlement of northeastern North Carolina, the area now known as Currituck County was home to the Poteskeet Indian Tribe. Although the Poteskeet's main village was located on the mainland, they used the northern Outer Banks, including the area now within the Reserve, as hunting and fishing grounds. Oyster shell middens and pottery fragments found at several locations in the northern Outer Banks are evidence that the Poteskeet used this area (Gale 1982). As English colonists began to settle in the area, documents dictate several nonviolent disputes over territory with the Poteskeet. By 1730, the Poteskeet had mostly disappeared from the Currituck area (Gale 1982).

B: Colonial Uses

In 1584, the English made their first attempt at settlement in the New World on Roanoke Island, approximately 42 miles (67.5 km^2) to the south. Despite the failure of this first colonization attempt, the English made a permanent settlement in southeastern Virginia. From there, the English began spreading to the south and settling in Currituck by the late seventeenth century. Like the Native Americans, the English also lived on the mainland. They used the banks for feeding livestock, fishing and hunting (Gale 1982).

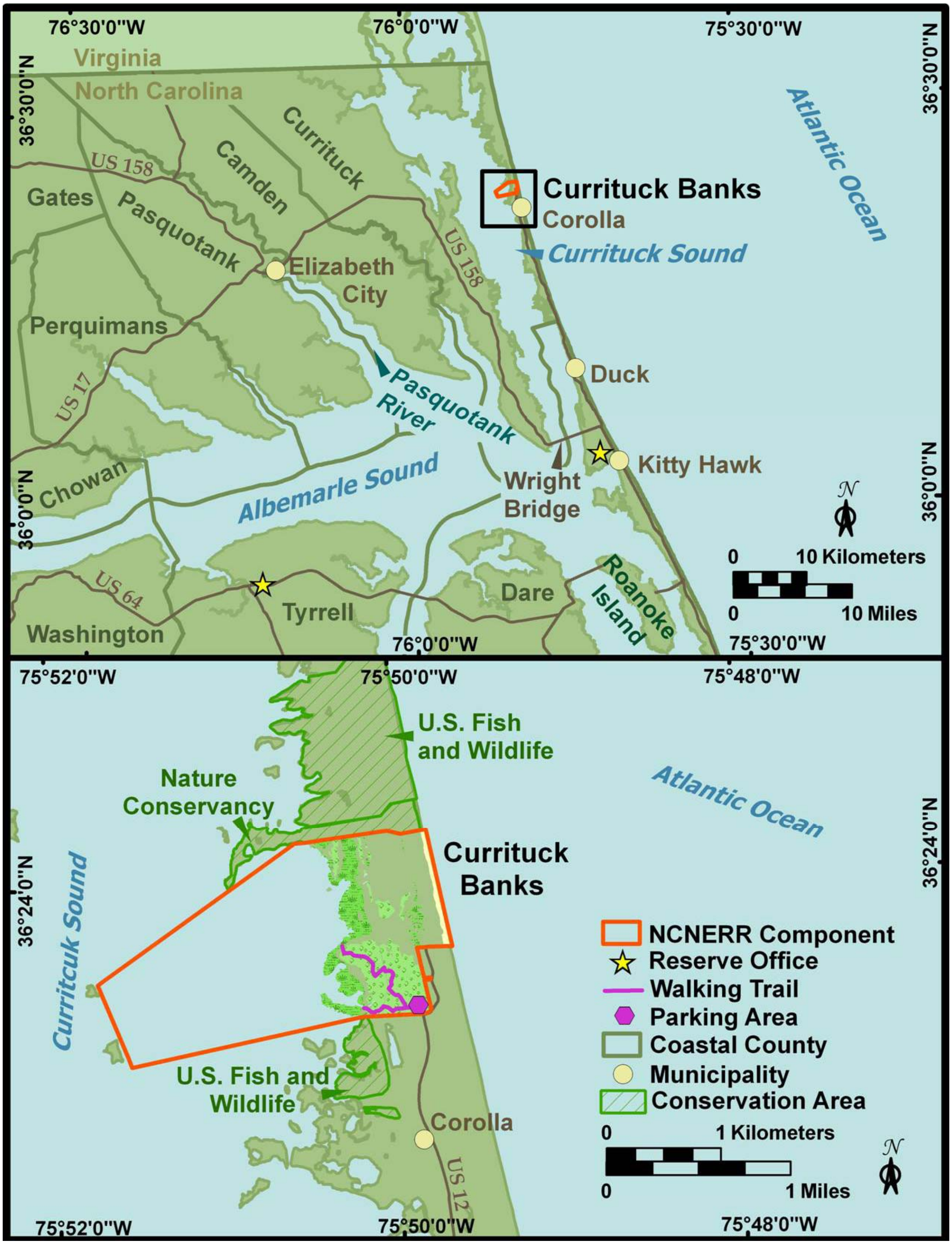


Figure 2.1: Currituck Banks location. The bottom panel shows a close-up of the Currituck Banks Reserve Component.

C: Waterfowl Hunting

Many ocean inlets existed throughout the history of the northern Outer Banks, however, by 1828, New Currituck Inlet, the last of the inlets, closed. This caused a transformation in the Currituck Sound from a high salinity estuarine environment to a low salinity estuarine environment (see Section 2.4). Along with this change, shellfish beds began to vanish; increased growth of SAV began and brought with it an increase in waterfowl to the area. Because of this increase in waterfowl, the area became known throughout the nation as a prime waterfowl hunting ground. This began the development of many hunt clubs in the area. The first of these hunt clubs was the Currituck Hunting Club in 1857. Most of these clubs were made up of wealthy nonresidents. The clubs assembled large tracts of land to preserve waterfowl feeding areas and to ensure a continuous bounty of geese, ducks and migratory game birds. (Gale 1982). During the Civil War and the years after, many people visited Currituck and enjoyed dinners of ducks and geese killed in Currituck Sound (Bates 1985). Around 1870, inquiries began coming in for available waterfowl to be shipped to large northern cities and the commerce was welcomed (Bates 1985). By the mid 1900s due to hunting pressure and declines in the SAV, the populations of migratory birds declined dramatically in Currituck sound, and the use of the area as a hunting ground also decreased.

D: Life Saving Stations and Lighthouses

During the 1800s many ships wrecked along the North Carolina coast. The federal government launched a two-part program to build lighthouses with powerful lights close enough to give ships continued guidance and to assist sailors by providing life saving services. This forerunner to the Coast Guard, called the U.S. Life Saving Service, was established in 1874 (Mobley 1994). Life saving stations were constructed and the U. S. Light House Board began erecting lighthouses to help mariners navigate the treacherous waters off the Outer Banks. The region near Currituck Banks had both a life saving station and a lighthouse (Mobley 1994). In 1873, construction began on the Currituck Beach Lighthouse. The lighthouse was completed and lit on December 1, 1875. In 1874 the Jones Hill Life Saving Station was constructed just east of the Currituck Beach Lighthouse site. This station was later renamed the Currituck Beach Life Saving Station as Jones Hill was renamed to Corolla in 1895 when a U. S. Post Office was erected. In 1915 the Life-Saving Service was merged with the Revenue Cutter Service to form the U.S. Coast Guard. Throughout the early part of the 20th century, modern Coast Guard Stations slowly replaced the life saving stations. The Light House Board was transformed into the U.S. Light House Service in 1910 and eventually also merged with the U.S. Coast Guard in 1939.

E: War Uses

The area of the outer banks where Currituck Banks is located was not as heavily used during war time as other areas of the coast. However, during the Revolutionary War, Civil War, and World War II, the area did see some military action. During the Revolutionary War, the Carolina coast was vital to the colonist. The large British ships could not navigate the small shifting sands of the North Carolina inlets. Local mariners could, allowing much needed supplies for the Confederate war effort to be brought in through North Carolina ports. During the Civil War the North Carolina ports again became critical supply routes for the Confederacy. Most of this activity occurred farther south (see Chapter 3-5) but some skirmishes did occur in the Northern Outer Banks region. Roanoke Island was a Confederate stronghold that was taken by the Union army after a fierce battle in 1862. Union forces held Roanoke Island, and most of the Outer Banks, for the rest of the Civil War (Campbell 2005). During World War II, the U.S. Coast Guard used the area near Currituck Banks as a training ground. Several hundred sailors were brought to the Corolla area. Barracks were built near the lighthouse and former life saving station. The waters offshore of Currituck Banks were used by German U-boats. During the war, residents were instructed to keep their house lights off and windows closed to prevent the U-boat captains from using them as a point of reference.

2.3: Climate

The weather of Currituck Banks is typical of a maritime climate on the Outer Banks where the ocean has a strong moderating effect on temperature compared to the mainland areas. Climatologically, Currituck Banks is classified as Subtropical with humid, warm summers and mild winters. Currituck Banks is 15 miles (24 km) north of the U.S. Army Corps of Engineers Field Research Facility in Duck, North Carolina, where atmospheric and oceanic data are collected (Figure 2.1). The average annual temperature for the region is 62 °F (17 °C). January is typically the coldest month with average daily temperatures (average of day and night) of 44 °F (7 °C) and July is normally the warmest month with average daily temperatures of 80 °F (27 °C). Because of the orientation of the Currituck Banks coastline, direct hurricane impacts are much less than the other more southern Reserve components. Nor'Easters tend to be more important at Currituck Banks because by the time the storms reach the northern Outer Banks they have had time to develop and strengthen. Several tropical systems have impacted the region since record keeping began. Table 2.1 lists the tropical systems that have passed within 65 nautical miles of Currituck Banks since 1955.

Currituck Banks precipitation data was inferred from the climate data available from NOAA for Norfolk, Virginia and Elizabeth City, N.C. The average annual precipitation for Currituck Banks based on data from 1971-2000 is 46.98 inches (119.3 cm). The wettest month is September and the driest month is October (Figure 2.2). The wettest year on record since 1871 occurred in 1889 with over 70 inches (177.8 cm). The driest year on record since 1871 occurred in 1986 with 26.5 inches (67.3 cm) of precipitation (Table 2.2).

Table 2.1: Tropical storms passing within 65nm of Currituck Banks since 1955

Storm	Date	Name	Wind (kts)	Minimum Pressure (mb)	Classification
1	Aug 1955	Connie	70	965	Category 1 hurricane
2	Sept 1955	Ione	65	960	Category 1 hurricane
3	Sept 1956	Flossy	35		Extratropical
4	July 1959	Cindy	35		Tropical storm
5	July 1960	Brenda	50		Tropical storm
6	Sept 1960	Donna	90		Category 2 hurricane
7	Sept 1961	Not Named	35		Tropical storm
8	Sept 1964	Cleo	40		Tropical storm
9	Sept 1964	Dora	50	998	Tropical storm
10	Oct 1964	Isbell	40	1000	Extratropical
11	June 1965	Not Named	30		Extratropical
12	Sept 1967	Doria	55	990	Tropical storm
13	June 1968	Abby	25		Tropical depression
14	Aug 1969	Camille	30		Tropical depression
15	May 1970	Alma	25	1003	Extratropical
16	Aug 1970	Not Named	30	1011	Tropical depression
17	Aug 1971	Doria	55	989	Tropical storm
18	Oct 1971	Ginger	30		Tropical depression
19	June 1972	Agnes	45		Tropical storm
20	July 1979	Bob	20	1011	Tropical depression
21	July 1981	Bret	50	1000	Tropical storm
22	Aug 1981	Dennis	60	997	Tropical storm
23	June 1982	Subtropical 1	60	992	Subtropical storm
24	Sept 1983	Dean	55	1009	Tropical storm
25	Sept 1984	Diana	50	1000	Tropical storm
26	Aug 1985	Danny	25	1012	Extratropical
27	Sept 1985	Gloria	90	942	Category 2 hurricane
28	Aug 1986	Charley	70	987	Category 1 hurricane
29	Sept 1992	Danielle	55	1001	Tropical storm
30	June 1995	Allison	40	992	Extratropical
31	June 1996	Arthur	35	1005	Tropical storm
32	Oct 1996	Josephine	45	986	Extratropical
33	July 1997	Danny	40	1000	Tropical storm
34	Aug 1998	Bonnie	75	985	Category 1 hurricane
35	Sept 1998	Earl	50	998	Extratropical
36	Sept 1999	Floyd	70	967	Category 1 hurricane
37	Sept 2000	Helene	40	1008	Tropical storm
38	June 2001	Allison	25	1006	Subtropical depression
39	Oct 2002	Kyle	40	1009	Tropical storm
40	Aug 2004	Bonnie	25	1008	Tropical depression
41	Aug 2004	Charley	60	1000	Tropical storm
Data from the NOAA – Coastal Services Center					

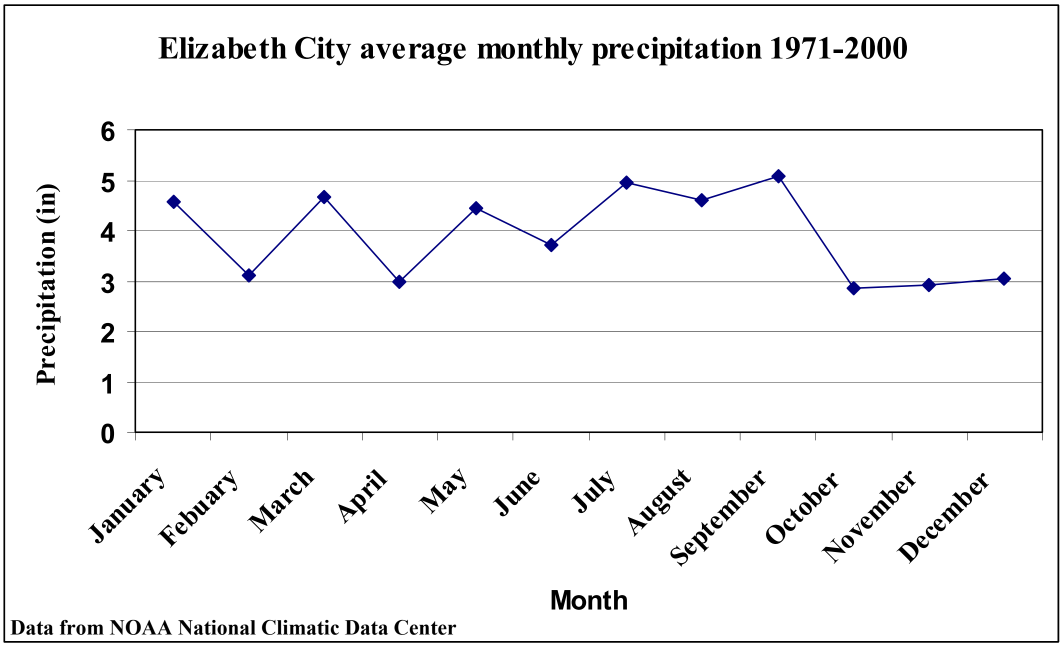


Figure 2.2: Elizabeth City average monthly precipitation 1971-2000.

Table 2.2: Top ten highest and lowest annual precipitation amounts for Norfolk, VA recorded 1892 – 2004

Top 10 highest precipitation amounts 1871 – 2004		
Rank	Precipitation (in)	Date
1	70.72	1889
2	69.14	1877
3	64.96	1979
4	63.25	1871
5	61.76	2003
6	59.70	1937
7	57.90	1893
8	57.78	1958
9	57.71	1964
10	57.67	1882
Top 10 lowest precipitation amounts 1871 – 2004		
Rank	Precipitation (in)	Date
1	26.48	1986
2	26.67	1965
3	26.91	1930
4	30.36	1921
5	30.90	1918
6	32.00	1931
7	32.21	1923
8	32.36	1976
9	32.89	1919
10	33.36	2001
Data from NOAA National Climatic Data Center		

2.4: Geological Processes

Currituck Banks is part of a barrier spit that extends 30 miles (48 km) from Virginia Beach, VA. The geomorphic attributes of this area include gentle to moderate slope, coarse to medium grain sediments, high profile islands, low frequency of high waves, slowly eroding coastlines, and generally wide lagoons and wide islands (Kochel et al. 1985). At current time, this spit is continuous and the sound behind the barrier, Currituck Sound, is predominately fresh in nature. However, through geologic time, inlets have formed and closed within the barrier spit. During an open inlet period, Currituck Sound is mostly marine in nature and very similar to the sounds bordering the other Reserves. However, during closed inlet periods, as is currently the case, Currituck Sound is uniquely fresh in nature. The inlet cycle is governed by litoral sediment supply moving from North to South along the spit, by storm processes and sea level.

The sediments that comprise the barrier spit are very similar to those that make up the rest of the Carolina Outer Banks. They consist of both Recent (less than ~11,550 years old) and Pleistocene (~1.8 million to ~11,550 years before present) sediments. The Pleistocene sediments represent ancient sand shoals that have been pushed landward by oceanic processes. The recent sediments represent terrigenous material that has been transported from upland areas by rivers and wind.

The entire barrier spit that Currituck Banks is a part of is still moving landward. Evidence to support this is found in the exposed peat layers on the beach front that are residuals from ancient maritime forests which were once located on the back of the island. As the island has moved landward these areas are transposed to the beach front where tidal action exposes the ancient tree roots and peat layers.

2.5: Hydrology and Water Quality

A: Ocean Side

a: Hydrology

The nearest tide gauge to Currituck Banks is located at the U.S. Army Corps Field Research Station in Duck, N.C. (Figure 2.1). This tide gauge is maintained through the NOAA - Center for Operational Oceanographic Products and Services. Based on data from this location, tides on the ocean side of Currituck Banks are mesotidal and average 3.2 feet (0.6m) a day and are diurnal in nature. The general flow offshore is from north to south due to the Labrador Current (Figure 1.3). The cool Labrador Current keeps the area around Currituck Banks a few degrees cooler than water south of Cape Hatteras, which is influenced by the warm water Gulf Stream. The near shore currents move sediment on and off the beach. This process is enhanced during coastal storms.

b: Water Quality

Ocean side water quality is monitored by the North Carolina Department of Environmental Health Shellfish Sanitation and Recreational Water Quality Section. They monitor for enterococcus bacteria (an indicator organism whose presence is correlated with that of others that can cause illness in humans) to determine if swimming advisories should be posted at several locations in and around Currituck Banks. Limits for enterococcus are based on the level of use a particular beach receives. A Tier 1 area is defined as receiving daily use during swimming season (April – September). Tier 1 beaches shall not exceed either: (1) A geometric mean of 35 enterococci per 100 ml of water, that includes a minimum of at least five samples collected within 30 days; or (2) A single sample of 104 enterococci per 100 ml of water. There are two Tier 1 sampling locations, Site N1 located directly adjacent to Currituck Banks and Site N2 located just south of the Reserve on the beach across from the lighthouse in Corolla (Figure 2.3).

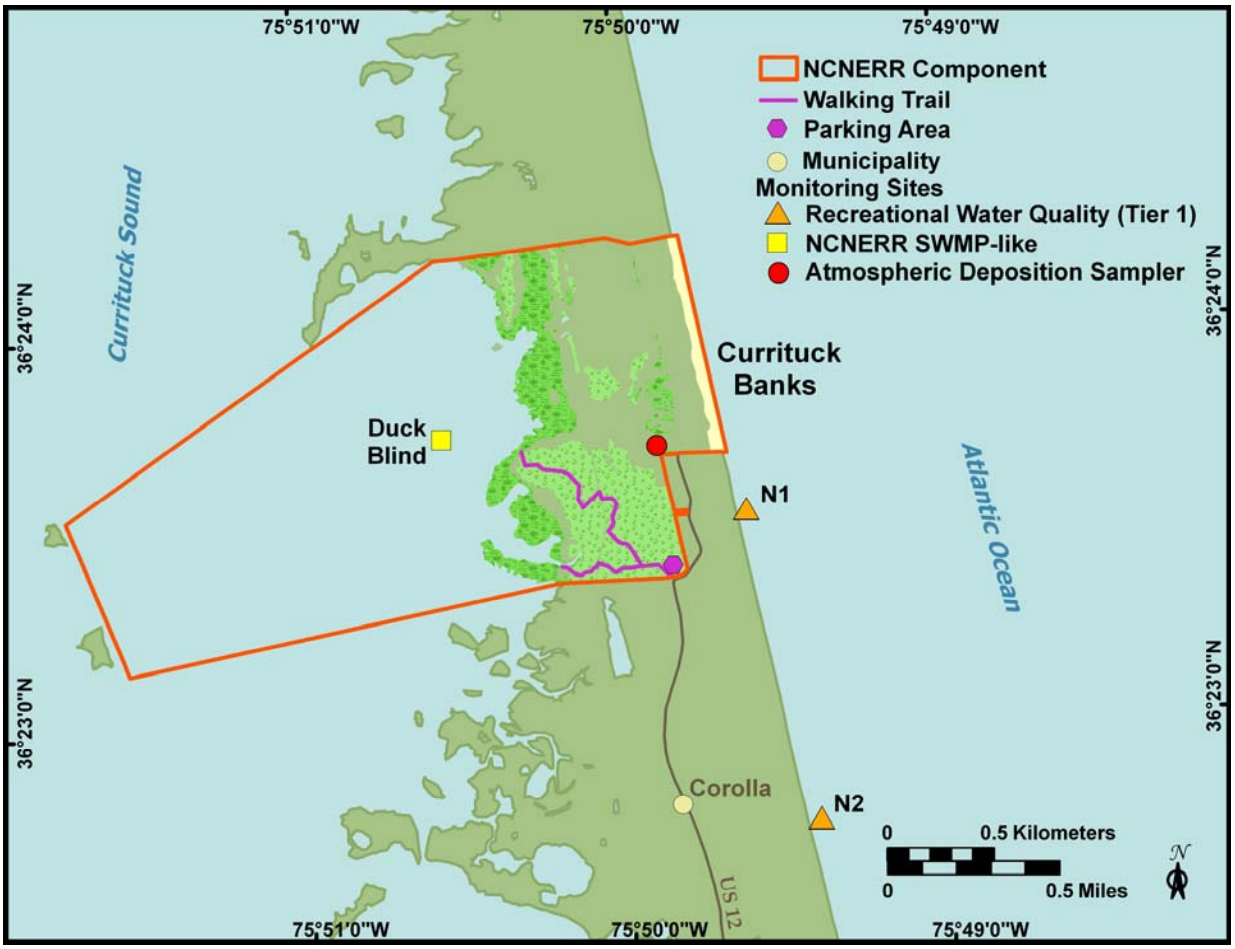


Figure 2.3: Water quality monitoring locations at Currituck Banks.

Based on data from these locations, the water quality along the ocean side of Currituck Banks is generally good in nature. Enterococci levels are usually very low (less than 25) however, single sample values are occasionally very high (Figure 2.4). These high values are of concern because they violate the state standard for Tier 1 beaches, and represent a potential risk to public health. As the population continues to increase and the development in the northern Outer Banks continues (see Section 2.10), the water quality on the ocean side of Currituck Banks could get worse. This is an important issue for the municipalities along the North Carolina northern Outer Banks because the primary source of income in these areas is tourism. Tourists would be

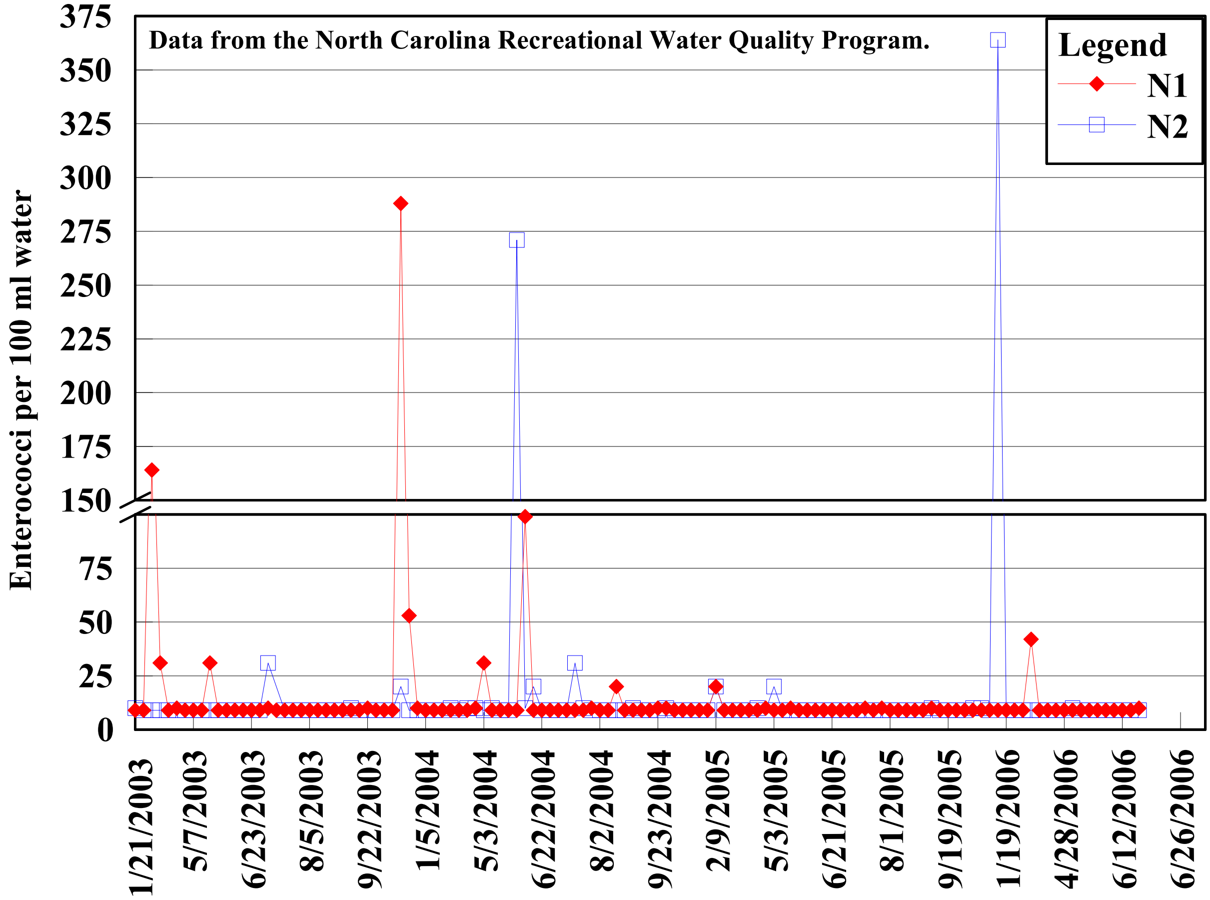


Figure 2.4: Enteroccoci data from the Tier 1 locations near Currituck Banks.

discouraged from visiting the area if there are continual swimming advisories and beach closures associated with fecal contamination.

B: Sound Side

a: Hydrology

The sound side of Currituck Banks is located within the Pasquotank River Basin (Figure 2.5). Tidal influence on the sound side is almost completely muted by the long distance between Currituck Banks and the nearest inlet, Oregon Inlet, which is located about 45 miles (72 km) away. Currituck Sound is approximately 35 miles (56 km) long, varies from 4 to 15 miles (6.5 to 24 km) wide, and is extremely shallow averaging 5 ft (1.5 m), and supports large amounts of SAV. Water movement in Currituck Sound is driven primarily by wind. This means that the water levels in Currituck Sound can change dramatically and rapidly in response to changes in the wind pattern. North winds tend to blow water out of the sound and southerly winds tend to force water into the sound. Because of this relationship between wind direction and water level, water levels tend to be highest in summer when winds predominately blow from the south-

southwest, and tend to be lowest in the winter when winds predominately blow from the north-northeast (Caldwell 2001).

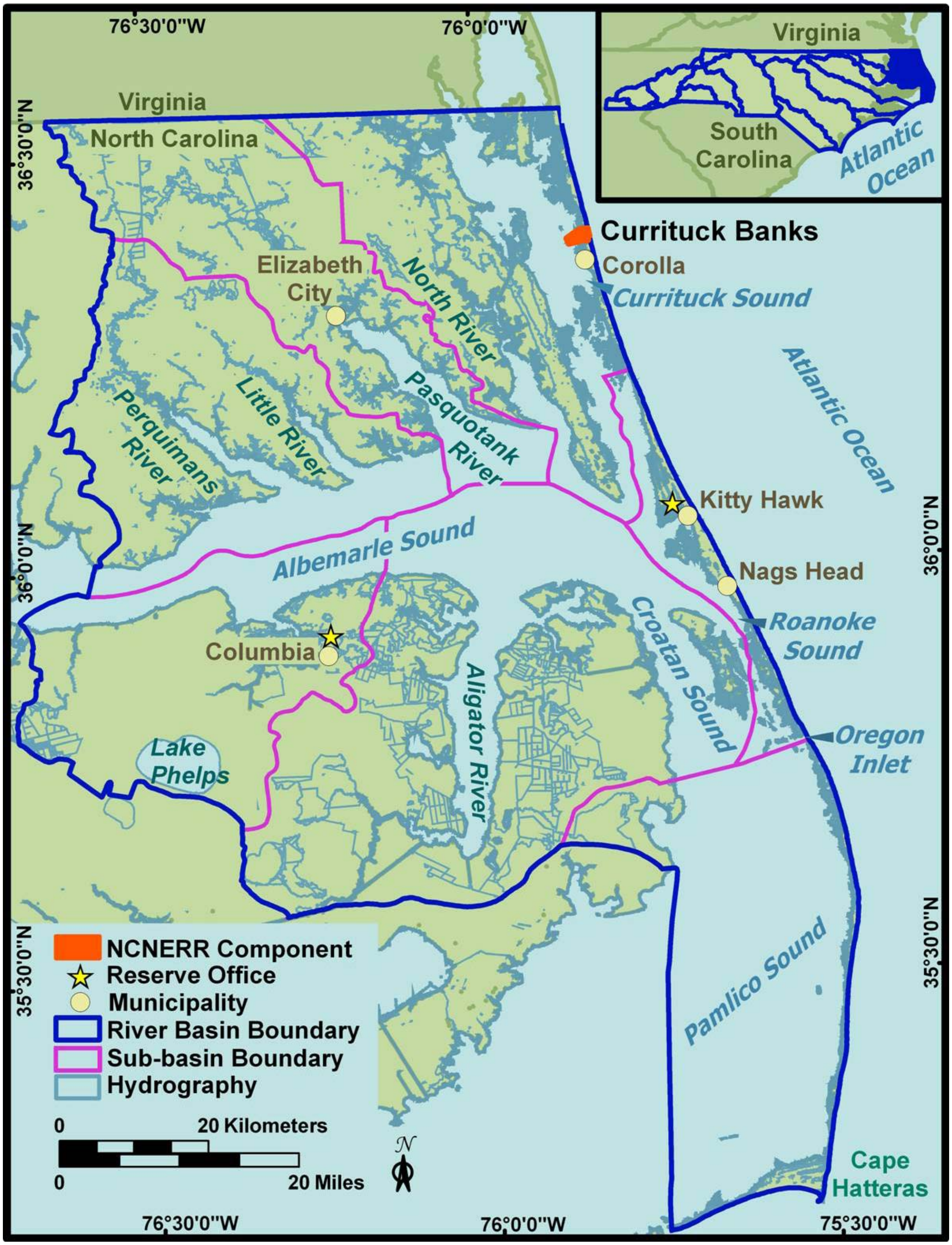


Figure 2.5: Pasquotank River Basin map.

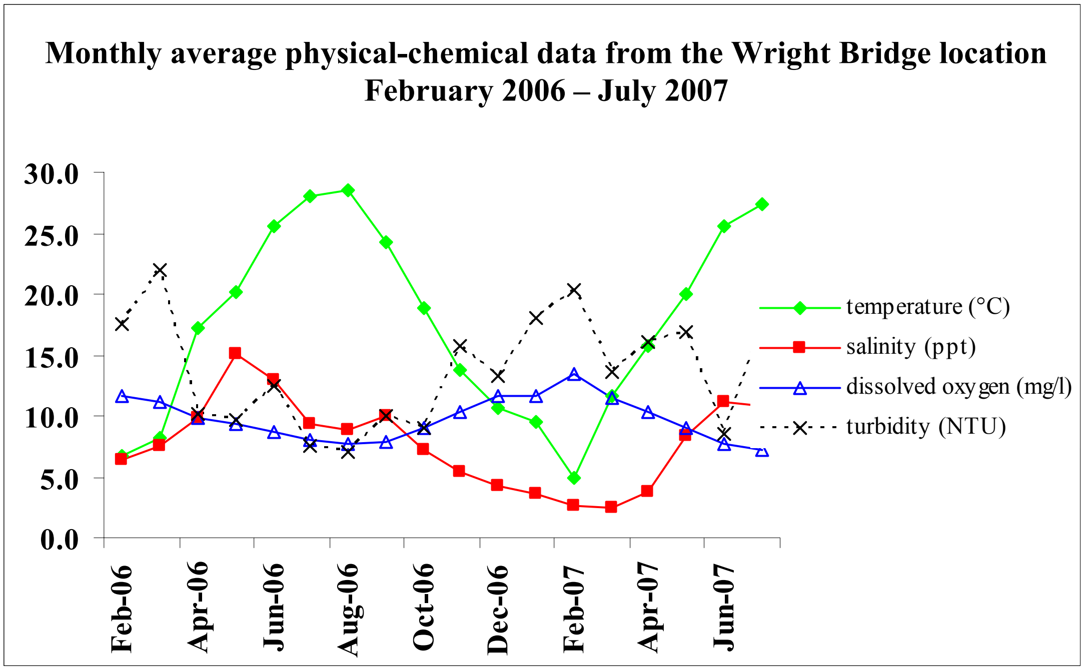
Salinity levels in the sound vary from essentially 0 up to 20 ppt, but average around 3.5 ppt (Caldwell 2001). Salinity shows a seasonal signal with higher values observed in the sound during summer due to the influx of marine waters from the sounds to the south. Currituck Sound empties into the larger Albemarle Sound at Kitty Hawk and is connected to the Chesapeake Bay through two canals in southern Virginia. These Chesapeake Bay canals are a source for high salinity water for the upper Currituck Sound during strong north wind events (Bales and Skrobialowski 1994). Currituck Sound is generally well mixed due to its shallow nature and can completely ice over during hard winters.

b: Water Quality

Water quality in Currituck Sound is heavily dependent upon the above hydrology. This is important as the spatial coverage of the SAV in the sound has been decreasing in recent years. The leading suspected cause for this decline is decreased water quality (Caldwell 2001). SAV issues are one of the focus areas for NCNERR in the Northern region. As such, understanding the water quality within Currituck Sound is a high priority issue. To address this issue, NCNERR as part of a larger group has been monitoring water quality within Currituck Sound since 2006. Two SWMP-like water quality monitoring stations were established. One is located on the channel guide of the Wright Memorial Bridge connecting Kitty Hawk with the mainland (Figure 2.1) and the other is located within the boundaries of Currituck Banks on a duck blind (Figure 2.3). Both were equipped with instruments made by Yellow Springs Instruments that measure: dissolved oxygen, pH, temperature, conductivity, salinity and turbidity. The Wright Bridge instrument is deployed at about 3.5 ft (~1 m) depth and in the middle of the sound. The Duck Blind location instrument is deployed at about 1 ft (~0.3 m) and very close to the eastern shore of Currituck Sound. This arrangement provides NCNERR coverage of both the central deeper mainstem portion of Currituck Sound (Wright Bridge location) and the shallow litoral areas. In addition to the physical-chemical data, water samples have been collected from the two stations once a month and analyzed for nutrients, total suspended solids, secchi depth and Chlorophyll *a*. These data coupled with that from the other project team members will be used to construct a hydrologic model for Currituck Sound. The model will then be used to predict how the Sound will respond to various potential future scenarios.

The monthly averaged physical-chemical data from the two SWMP-like sampling stations in Currituck Sound is presented in Figure 2.6. The data from the two stations demonstrate how the salinity levels in the sound fluctuate especially at the mouth (Wright Bridge location). Salinity is highest at the Wright Bridge location in summer. The highest salinity levels at the Duck Blind location also occurred in summer, but overall salinity was much lower at the Duck Blind location (2-5 ppt) compared to the Wright Bridge location (4-15 ppt). The salinity levels at the Duck Blind are lower than those at the mouth of Currituck Sound due to two factors. First the Duck Blind location is much farther away from the nearest ocean inlet, thus it is farther away from the primary source of salty water, the ocean. Second, it is closer to the land, making it more impacted by stormwater runoff. Both these factors make the sound waters at the Duck Blind location fresher than the water at the Wright Bridge.

Turbidity also shows extreme variations between months. Turbidity at the Wright Bridge location was highest in the winter months. Winter is also the time of year when the strongest winds occur in the region. This data suggest that the turbidity in the system is mainly caused by resuspended sediments. There is no apparent seasonal turbidity signal at the Duck Blind location. This is most likely because the seasonal signal is obscured by pulses of turbidity associated with both runoff events caused by rain, and by wind. The shallow nature of the Duck Blind location also means that lower energy is required to disturb the bottom. All of these factors help explain the more frequent turbidity spikes at the Duck Blind location.



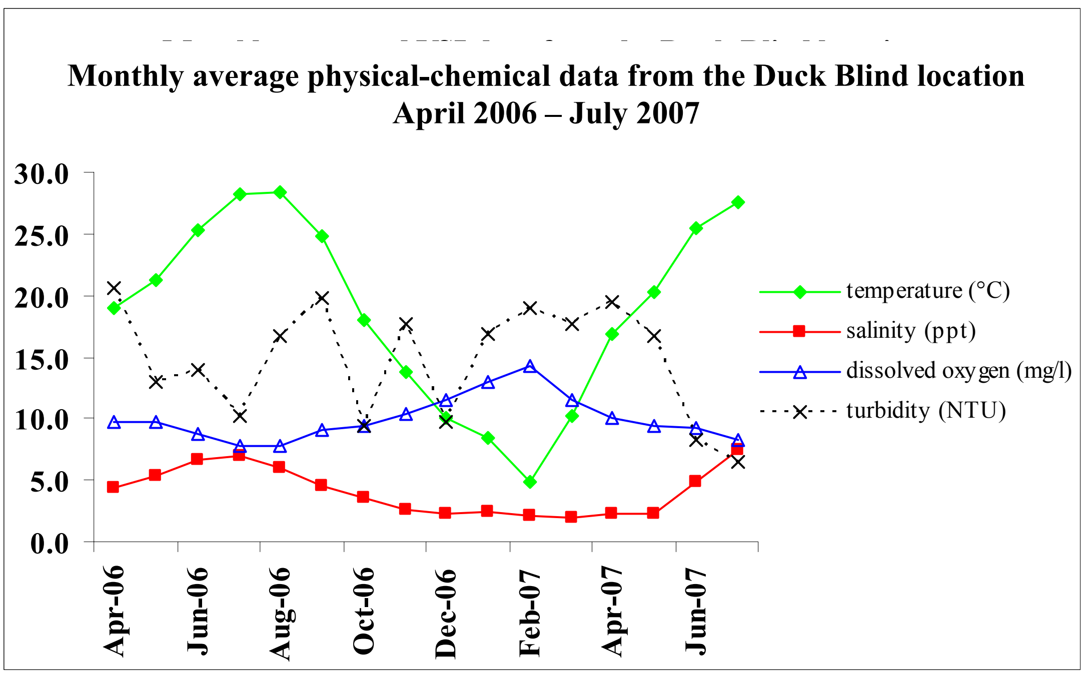


Figure 2.6: Monthly averaged physical-chemical data from the NCNERR SWMP-like Currituck Sound water quality stations.

Turbidity levels are extremely important because they impact how much light penetrates the water column. Suitability of habitats for SAV are determined by light and parameters that modify light such as epiphytes, total suspended solids, chlorophyll and nutrient concentrations (Koch 2001). Thus, high turbidity values are not favorable for SAV growth and recovery. Turbidity is just one factor that affects water column light penetration. Secchi depth is a measurement that quantifies all the factors that affect light penetration and provides an estimate for the lowest depth at which photosynthetic plants can grow. Secchi depths for the southern end of the sound near the Wright Bridge (Figure 2.1) range from 1.2 to 3.2 ft (0.375 to 1 m) and average 2.25 ft (0.68 m). Secchi depths at the Duck Blind (Figure 2.3) range from 1.2 to 2 ft (0.375 to 0.625 m) and average 1.6 ft (0.5 m). Both these depths are shallower than the average depth for Currituck Sound which is 5 ft (1.5 m). Thus, there are many areas of the sound that are not capable of supporting SAV because of the lack of light. See Section 2.11 for maps showing where SAV is currently found within Currituck Sound.

The nutrient (NO_3^-, NH_4^+, PO_4^{-3}) and Chlorophyll *a* data from the two SWMP-like stations is presented in Figure 2.7. These data suggest that nutrient levels in the sound are usually quite low. Occasional pulses of nutrients do occur as seen in February and May 2007 (Figure 2.7). Higher nutrient pulses were observed at the Duck Blind location, which is closer to land, compared to the main stem Wright Bridge location. This suggests that the main nutrient sources for Currituck Sound are runoff from adjacent land and not the waters of the Albemarle Sound. The data in Figure 2.7 also show that the Chlorophyll *a* levels did not respond to the nutrient pulses. Three possibilities may be occurring in the sound to explain this. The sound's productivity may be primarily due to the SAV and thus the phytoplankton would not be expected to respond to nutrient pulses, the sound may be light limited, or the productivity spike associated with the nutrient additions may occur at a different location than where the water quality monitors are located. Future research needs to examine this question, and help explain how the system responds to nutrient pulses.

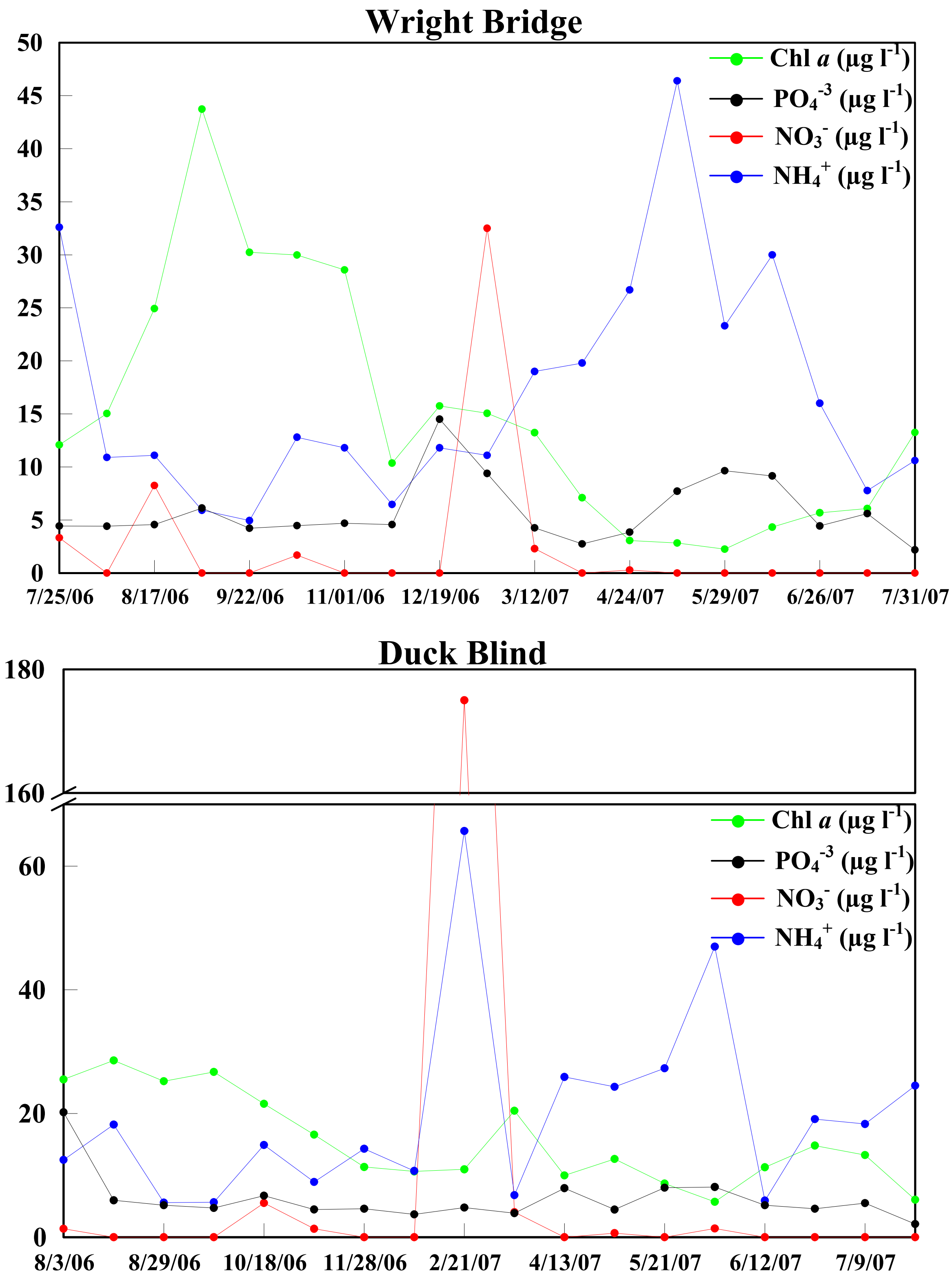


Figure 2.7: Nutrient and Chlorophyll a data from the NCNERR SWMP-like Currituck Sound water quality stations.

2.6: Habitat Types

A primary objective of SWMP Phase 3 is to evaluate changes over time in estuarine habitats and coastal land cover. To accomplish this, the types and locations of habitats within the Reserve must be periodically quantified. The habitat types of Currituck Banks were initially characterized in 1994. This effort used a very general classification system that only broke habitats down into very broad categories. These habitat types included the open water of Currituck Sound, irregularly exposed flats, marshes, maritime shrub thicket and forest, ponds, dunes and beaches (Table 2.3). Figure 2.8 shows the resultant map from this effort.

Table 2.3: Currituck Banks 1994 habitat classifications

Habitat	Description
Shallow waters of Currituck Sound	Open Oligohaline water with areas of aquatic vegetation, including sago pondweed, widgeon grass and Eurasian water milfoil.
Irregularly exposed mud flats	Open mud or sand flats exposed during irregular low wind tides.
Marshes	Mosaic of brackish, transitional and freshwater marshes. Vegetation includes black needlerush, giant cordgrsss, cattails, sedges and rushes.
Maritime shrub thicket	Upland areas with shrubs that include wax myrtle, bayberry, youpon.
Maritime evergreen forest	Upland areas with mixed mature forest, with live oaks and loblolly pines dominant.
Dunes	Upland areas stabilized by grasses such as sea oats, American beach grass and beach panic grass.
Interdune ponds	Seasonal or permanent open water in depressions within upland.
Beaches	Gently sloping, open intertidal sandy beaches.

However, this assessment provided only minimal information regarding habitat types and function. To more accurately and methodologically account for the various habitat types within the Reserve components, in 2005 NCNERR participated as a pilot Reserve for the NERRS habitat and land use classification system. This effort categorized the habitats within the Reserves using a much improved classification system (Appendix 4).

The updated habitat map for Currituck Banks is presented at the subclass level in Figure 2.9. Areal statistics for habitat occurrence were calculated from the digital classification data and are provided as acreage and the percentage of total acres mapped for each habitat subclass (Table 2.4). Subtidal areas were not included in this assessment. Visual observations were made during field surveys to document predominant plant species for each habitat subclass. These data provide a baseline framework for conducting more in-depth inventories of vegetation composition and conditions. Habitat subclasses at Currituck Banks are described in the following paragraphs, with representative photographs presented in Appendix 4.

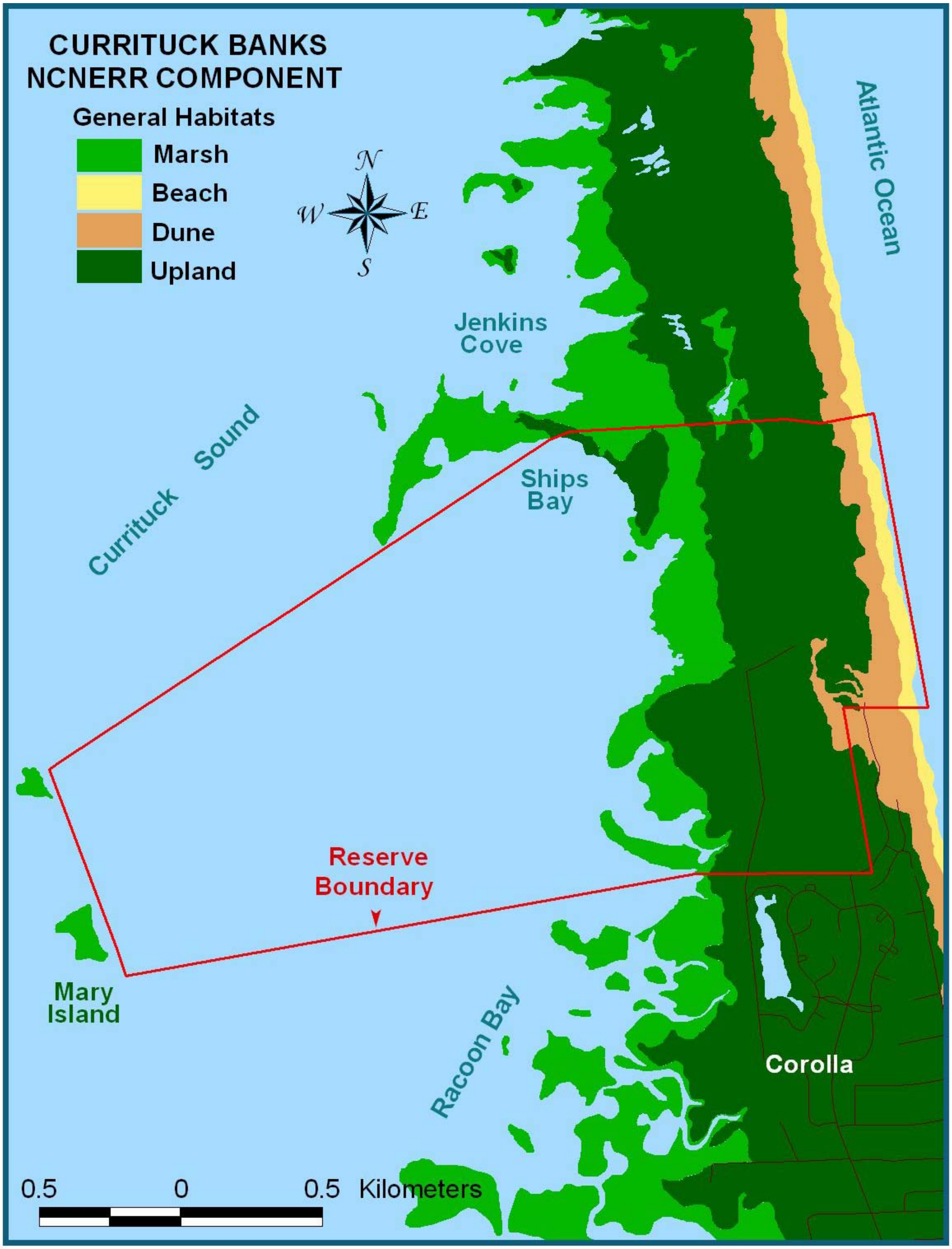


Figure 2.8: Habitat map from 1994 for Currituck Banks.

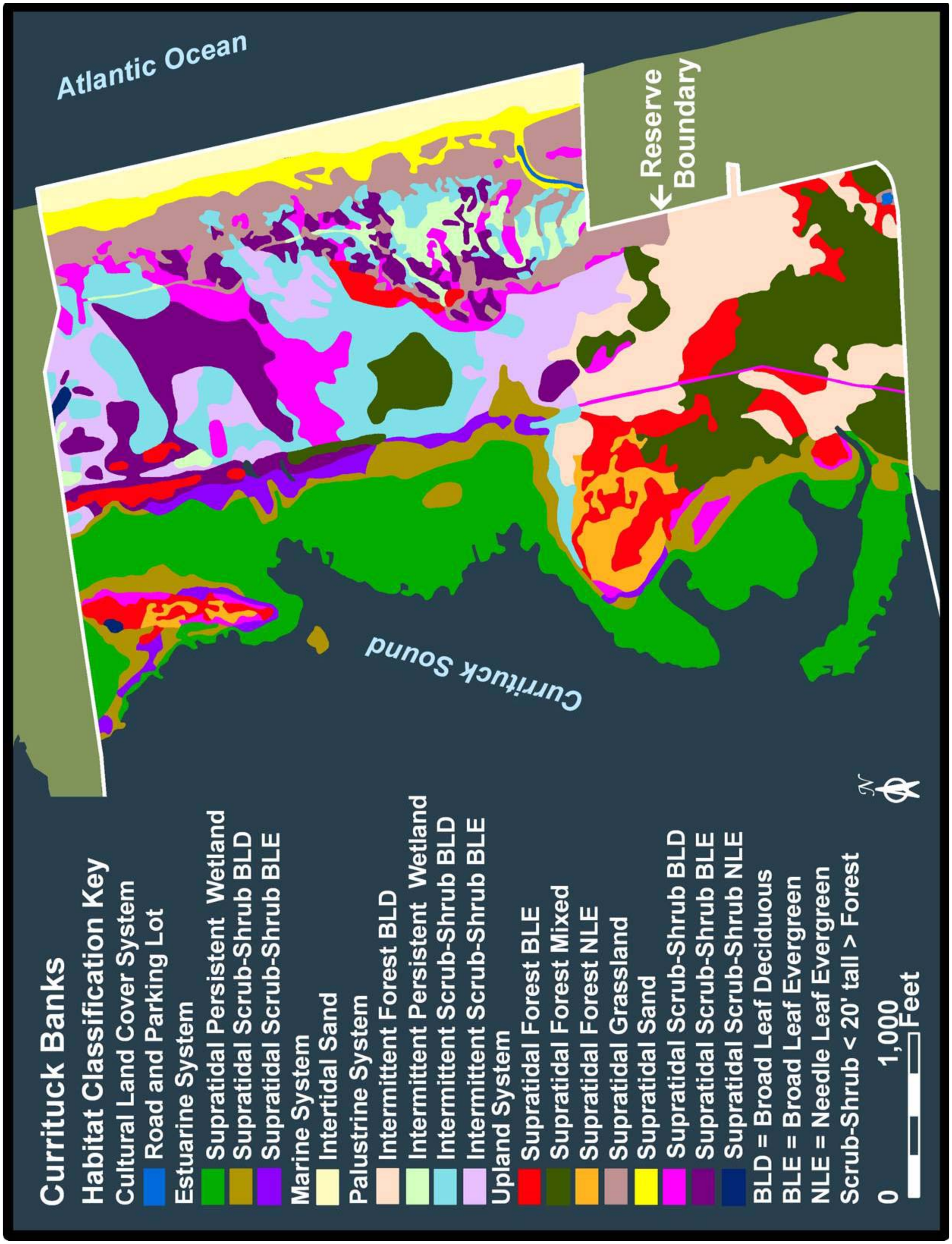


Figure 2.9: Currituck Banks 2004 habitat classification presented at the subclass level.

Table 2.4: Currituck Banks 2004 habitat classifications areal statistics

Habitat Subclass	Area (Acres)	% of Total
Estuarine Supratidal Persistant Wetland	55.06	17.32
Upland Supratidal Forest Mixed	35.08	11.04
Palustrine Intermittent Scrub-Shrub Broad Leaf Deciduous	32.58	10.25
Palustrine Intermittent Forest Broad Leaf Deciduous	29.91	9.41
Upland Supratidal Grassland	25.19	7.93
Upland Supratidal Scrub-shrub Broad Leaf Evergreen	23.71	7.46
Upland Supratidal Forest Broad Leaf Evergreen	20.71	6.52
Palustrine Intermittent Scrub-Shrub Broad Leaf Evergreen	19.75	6.21
Upland Supratidal Scrub-shrub Broad Leaf Deciduous	18.03	5.67
Marine Intertidal Sand	14.05	4.42
Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous	12.52	3.94
Upland Supratidal Sand	9.98	3.14
Upland Supratidal Forest Needle Leaf Evergreen	6.91	2.17
Palustrine Intermittent Persistant Wetland	6.74	2.12
Estuarine Supratidal Scrub-Shrub Broad Leaf Evergreen	6.68	2.10
Upland Supratidal Scrub-shrub Needle Leaf Evergreen	0.52	0.16
Paved Road	0.28	0.09
Sand Parking Lot	0.11	0.03
Total Mapped Habitat Area	**317.81***	**100.00**
* Subtidal areas not included		

- The largest subclass within the Currituck Banks Component was Estuarine Supratidal Persistant Wetland, comprising 55 acres and 17% of the total non-aquatic habitat area. This habitat, located along Currituck Sound, is irregularly flooded by brackish water during wind-driven high tides. These areas are expanses of Giant Cordgrass (*Spartina cynosuroides*), with stands of Black Needle Rush (*Juncus roemerianus*) and Cattail (*Typha* sp.).

- The second most common habitat was Upland Supratidal Forest Mixed, which covered 35 acres and 11% of the total area. Stands of this subclass were found in the south and center portions of the Reserve. Vegetation consists of a mix of Loblolly Pines (*Pinus taeda*) and broad leaf trees, including Live Oak (*Quercus virginiana)*, Yaupon (*Ilex vomitoria*), Wax Myrtle (*Morella cerifera* or *Myrica cerifera*) and Laurel Oak (*Quercus laurifolia*).

- Palustrine Intermittent Broad Leaf Deciduous communities of Scrub-Shrub (33 acres, 10% of total) and Forest (30 acres, 9% of total) were the next most prevalent habitats. Vegetation was designated Scrub-Shrub or forest when, respectively, less or greater than 20’ in height. These areas were found in depressions in the middle of the

Reserve, between the dune ridge to the east and marshes along Currituck Sound to the west. Species include Red Maple (*Acer rubrum),* Carolina Willow (*Salix caroliniana*), Willow Oak (*Quercus phellos*), Persimmon *(Diospyros viginiana*) and Black Gum (*Nyssa sylvatica*).

- Upland Supratidal Grassland (25 acres, 8% of the total mapped habitat) was located adjacent to the Atlantic Ocean beach. This area has greater than 30% vegetative cover, with a mixed community of perennial beach grasses such as Salt Meadow Hay (*Spartina patens)*, Sea Oats (*Uniola paniculata*), Inland Saltgrass (*Distichlis spicata*) and various species of *Panicum.*

- Two subclasses of Upland Supratidal Broad Leaf Evergreen each represented approximately 7% of the habitat area. Scrub-shrub (24 acres) and Forest (21 acres) are, respectively less or greater than 20 ft in height. These are mixed communities that include Live Oak (*Quercus virginiana*), Yaupon (*Ilex vomitoria*), Wax Myrtle (*Morella cerifera* or *Myrica cerifera*), and Laurel Oak (*Quercus laurifolia*). The Eastern Red Cedar (*Juniperus virginiana*), a needle leaf evergreen, is also present, though not dominant.

- Total habitat area included two subclasses with 6% each. Palustrine Intermittent Scrub-Shrub Broad Leaf Evergreen included 20 acres of mixed Sweet Bay (*Magnolia viginiana*), Red Bay (*Persea boarbonia*), Wax Myrtle (*Myrica cerifera*) and Dahoon Holly (*Ilex cassine*). Upland Supratidal Scrub-shrub Broad Leaf Deciduous consisted of 18 acres of Marsh Elder (*Iva frutescens*), Grounsel Tree (*Baccharis halimifolia*) and Northern Bay Berry (*Myrica pensylvanica*).

- Subclasses with 3 – 4 % each of the total area include 14 acres of Marine Intertidal Sand beach along the Atlantic Ocean, 12 acres of Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous containing mostly Sea Ox-eye (*Borrichia frutescens*) and Glasswort (*Salicornia spp.*) and 10 acres of Upland Supratidal Sand, commonly known as "sand dunes", adjacent to the beach. These areas are open, with ≤ 30% vegetative cover.

- Three subclasses each covered approximately 7 acres and 2% of the mapped habitat area. The Upland Supratidal Forest Needle Leaf Evergreen is composed primarily of Loblolly Pines (*Pinus taeda*) with a small unique stand of Longleaf Pine (*Pinus palustris*) at the north western boundary of the Reserve. Palustrine Intermittent Persistant Wetland, predominantly Salt Meadow Cordgrass *(Sparina patens),* exists in depressions in the south eastern portion of the Reserve. Estuarine Supratidal Scrub-Shrub Broad Leaf Evergreen habitat, found along the eastern edge of the Currituck Sound marsh, includes Sweet Bay (*Magnolia viginiana*), Red Bay (*Persea boarbonia*), Wax Myrtle (*Myrica cerifera*) and Dahoon Holly (*Ilex cassine*).

- Subclasses with less than 1% of the total area each were Upland Supratidal Scrub-Shrub Needle Leaf Evergreen with 0.5 acres of short (≤ 20 ft) Loblolly Pines (*Pinus taeda*) and Eastern Red Cedar (*Juniperus virginiana*), as well as the Paved Road (0.3

acres) and Sand Parking Lot (0.1 acres) of the visitor access site at the south eastern border of the Reserve.

2.7: Plants

The plant communities present within the Currituck Banks Reserve are consistent with those found in other areas of North Carolina's northern Outer Banks. The dominant terrestrial plant species for each habitat subclass are listed in the preceding section. For a full species list refer to Appendix 5. Also found within the Currituck Banks boundary are large beds of submerged aquatic vegetation (See section 2.11 for a spatial coverage map). These communities provide good habitat for a variety of aquatic animals, which in turn attract and support migratory waterfowl.

The maritime forest community found within Currituck Banks is an extremely rare habitat. There are very few places within the North Carolina coastal area that still contain undisturbed maritime forest. These slow growing communities provide important habitat for many types of animals. Maritime forests contain unique assemblages of flora and fauna (Grand and Vernia 2002). The leaf litter produced by the forest is also an important soil building material. As the leaf litter accumulates on the forest floor over time peat is formed. This peat layer provides a nutrient rich environment that supports many other plant species. The North Carolina Natural Heritage Program list several plant species as significantly rare in Currituck County and one, the Carolina Grasswort (*Lilaeopsis carolinensis*), as threatened (Table 2.5)

The water areas within the Reserve contain large beds of SAV. The plants found within the Reserve mirror those found for all of Currituck Sound. Section 2.11 details efforts to map and identify SAV species within Currituck Sound.

2.8: Animals

Currituck Banks is home to a variety of animals. Since the Reserve is located just north of the transition between the Carolinian and Virginian biogeographic province, it potentially can support the fauna from both provinces. The well developed maritime forest of Currituck Banks provides habitat for many mainland species that otherwise would not be capable of surviving in the Currituck Banks area. The beach and marsh areas of Currituck Banks provide valuable wetland habitat that supports a myriad of species. Unfortunately, there has not been much work conducted in Currituck Banks relative to the fauna and the list below represents a very small percentage of the species that are present. The lack of comprehensive animal data for Currituck Banks is a gap that needs to be addressed with future research and monitoring. The North Carolina Natural Heritage Program lists several animal species as significantly rare or threatened in Currituck County (Table 2.5).

Table 2.5: Species of special concern in and near Currituck Banks

State Status Codes: E = Endangered, T = Threatened, SC = Special Concern, SR = Significantly Rare, L = range limited to North Carolina and adjacent states.

Federal Status Codes: E = Endangered, T = Threatened, FSC = Federal Special Concern.

Major Group	Scientific Name	Common Name	State Status	Federal Status
Vascular Plant	*Amaranthus pumilus*	Seabeach Amaranth	T	T
Vascular Plant	*Carex hormathodes*	A Sedge	SR-P	None
Vascular Plant	*Cladium mariscoides*	Twig-rush	SR-O	None
Vascular Plant	*Cyperus dentatus*	Toothed Flatsedge	SR-P	None
Vascular Plant	*Eleocharis montevidensis*	Sand Spikerush	SR-P	None
Vascular Plant	*Eleocharis rostellata*	Beaked Spikerush	SR-O	None
Vascular Plant	*Hudsonia tomentosa*	Sand Heather	SR-P	None
Vascular Plant	*Isoetes riparia*	Riverbank Quillwort	SR-P	None
Vascular Plant	*Leptochloa fascicularis var. maritima*	Long-awned Spangletop	SR-O	None
Vascular Plant	*Lilaeopsis carolinensis*	Carolina Grasswort	T	None
Vascular Plant	*Limosella australis*	Awl-leaf Mudwort	SR-P	None
Vascular Plant	*Ludwigia alata*	Winged Seedbox	SR-P	None
Vascular Plant	*Ludwigia brevipes*	Long Beach Seedbox	SR-T	None
Vascular Plant	*Myriophyllum pinnatum*	Cutleaf Water-milfoil	SR-T	None
Vascular Plant	*Ranunculus hederaceus*	Ivy Buttercup	SR-D	None
Vascular Plant	*Sagittaria weatherbiana*	Grassleaf Arrowhead	SR-T	FSC
Vascular Plant	*Torreyochloa pallida*	Pale Mannagrass	SR-P	None
Vascular Plant	*Trillium pusillum var. virginianum*	Virginia Least Trillium	E	FSC
Vascular Plant	*Vaccinium macrocarpon*	Cranberry	SR-P	None
Invertebrate Animal	*Euphyes dukesi*	Dukes' Skipper	SR	None
Invertebrate Animal	*Papilio cresphontes*	Giant Swallowtail	SR	None
Invertebrate Animal	*Poanes aaroni*	Aaron's Skipper	SR	None
Invertebrate Animal	*Satyrium favonius ontario*	Northern Oak Hairstreak	SR	None
Animal Assemblage	*Colonial Wading Bird Colony*	None	None	None
Animal Assemblage	*Gull-Tern-Skimmer Colony*	Colonial Waterbirds Nesting Site	None	None
Bird	*Charadrius melodus*	Piping Plover	T	T
Bird	*Coturnicops noveboracensis*	Yellow Rail	SR	None
Bird	*Egretta caerulea*	Little Blue Heron	SC	None
Bird	*Egretta thula*	Snowy Egret	SC	None
Bird	*Egretta tricolor*	Tricolored Heron	SC	None
Bird	*Haliaeetus leucocephalus*	Bald Eagle	T	T
Bird	*Laterallus jamaicensis*	Black Rail	SR	FSC
Bird	*Picoides borealis*	Red-cockaded Woodpecker	E	E
Bird	*Plegadis falcinellus*	Glossy Ibis	SC	None
Bird	*Sternula antillarum*	Least Tern	SC	None
Reptile	*Crotalus horridus*	Timber Rattlesnake	SC	None
Reptile	*Dermochelys coriacea*	Leatherback	E	E
Reptile	*Caretta caretta*	Loggerhead	T	T
Reptile	*Lampropeltis getula sticticeps*	Outer Banks Kingsnake	SC	None
Reptile	*Nerodia sipedon williamengelsi*	Carolina Water Snake	SC	None
Mammal	*Peromyscus leucopus easti*	Pungo White-footed Mouse	SC	None
Mammal	*Condylura cristata pop. 1*	Star-nosed Mole - Coastal Plain Population	SC	None
Mammal	*Trichechus manatus*	West Indian Manatee	E	E

Data from the North Carolina Natural Heritage Program

A: Invertebrates and Zooplankton

There is not much data available regarding the invertebrates and zooplankton found within the Reserve. The Natural Heritage Program lists four butterfly species, Dukes' Skipper (*Euphyes dukesi*), Giant Swallowtail (*Papilio cresphontes*), Aaron's Skipper (*Poanes aaron*) and the Northern Oak Hairstreak (*Satyrium favonius ontario*) as having special concern (Table 2.5).

Unfortunately, there has not been any monitoring to determine if these species are found in the Reserve. The soundside nearshore sediments support a myriad of benthic invertebrate animals including mussels, insect larvae, and crustaceans. These animals are an important food source for migratory waterfowl and fish.

B: Fishes

The oligohaline waters of Currituck Sound support many types of fresh and saltwater fish. A commercially important fishery for Striped Bass (*Morone saxatilis*) is present. Other important sportfish include Largemouth Bass *(Micropterus salmoides)*, Flounder (*Paralichthys dentalus*), Speckled Trout (*Cynoscion nebulosus*), and Red Drum (*Sciaenops ocellatus*). The sound supports several Sunfish species (*Lepomis sp.*), Crappie (*Pomoxis nigromaculatus* and *Pomoxis annularis*), Perch (*Perca flavescens* and *Morone Americana*) and several species of Catfish [Channel Catfish (*Ictalurus punctatus*), White Catfish (*Ameiurus catus*), Blue Catfish (*Ictalurus furcatus*), Bullhead Catfish (*Ameiurus sp.*)]. The American Eel, (*Anguilla rostrata*) can also be found in Currituck Sound. Juvenile eel, called elvers, are an important component in the diet of many predatory fish such as the Striped and Largemouth Bass.

C: Reptiles and Amphibians

The habitats of Currituck Banks support many types of reptiles and amphibians. Table 2.5 list five as having special or threatened status. Two of these are marine turtles, the Leatherback (*Dermochelys coriacea*) and Loggerhead (*Caretta caretta*). While turtles generally nest south of Currituck Banks, occasionally the ocean areas of Currituck Banks are used for nesting. The waters of Currituck Sound support many species of freshwater turtle. This makes Currituck Banks the only NCNERR component that supports both aquatic freshwater and marine turtles. The remaining species on the Natural Heriatage list are snake species, the Timber Rattlesnake (*Crotalus horridus*), the Outer Banks Kingsnake (*Lampropeltis getula sticticeps*), and the Carolina Water Snake (*Nerodia insularum*). In addition, many other snake species utilize the habitats at Currituck Banks. Some of the more common include the Black Racer (*Coluber constrictor*), Eastern Gater Snake (*Thamnophis sirtalis*), and Eastern Hognose Snake (*Heterodon platyrhinos*) and Rat Snake (*Elaphe obsoleta*). Green Anoles (*Anolis carolinensis*) and Six-lined Racerunners (*Cnemidophorus sexlineatus*) have also been observed in the Reserve.

The amphibians found in Currituck Banks are very similar to those found in other areas of North Carolina. The presence of the maritime forest habitat means that many mainland species not normally found in barrier island systems are present. Common frogs and toads found in Currituck Banks include the Eastern Spadefoot (*Scaphiopus holbrookii*), Southern Toad (*Bufo terrestris*), Green Treefrog (*Hyla cinerea*), Spring Peeper (*Pseudacris crucifer*), and Southern Leopard Frog (*Rana utricularia*). Salamander species are also probably present in the Reserve, but at current time there is no information available to verify this assumption.

D: Birds

Currituck Banks provides habitat to a great many species of birds. Migratory waterfowl including many types of Ducks and Geese utilize the sound waters within the Reserve for feeding. The marsh habitats of Currituck Sound support Belted Kingfishers (*Megaceryle* *alcyon*), Herons and Egrets (*Egretta sp.* and *Ardea sp.*), and Ducks. The maritime forest support many species of songbirds including Sparrows, Warblers, Finches, and Wrens. The ocean and dune areas of the Reserve support colonial nesting birds such as Plovers, and other shorebirds like Brown Pelicans (*Pelecanus occidentalis*), Gulls, Terns and Sandpipers (*Calidris sp.*). The Reserve is also home to several species of raptor including the Osprey (*Pandion haliaetus*), Bald Eagle (*Haliaeetus leucocephalus*), Red-tailed Hawk (*Buteo jamaicensis*), Great Horned Owl (*Bubo virginianus*) and Barred Owl (*Strix varia*). The endangered Red-Cockaded Woodpecker (*Picoides borealis*) has also been observed in the Reserve but, at present, there are not any active nesting trees.

E: Mammals

Currituck Banks is home to many mammal species. Three are listed in Table 2.5 as having special or threatened status: the Pungo White-footed Mouse (*Peromyscus leucopus easti*), the Star-nosed Mole (*Condylura cristata*), and the West Indian Manatee (*Trichechus manatus*). Only the first two are potentially found in the Reserve. The Manatee is listed only because occasionally one strays from the warm waters of Florida to more northern waters. No manatees have ever been documented within the boundaries of Currituck Banks.

The Reserve is home to many other common mammals including White Tail Deer (*Odocoileus virginianus*), Grey Squirrel (*Sciurus carolinensis*), Raccoon (*Procyon lotor*), River Otter (*Lontra Canadensis*), Eastern Cottontail Rabbit (*Sylvilagus floridanus*), Marsh Rabbit (Sylvilagus palustris) and Possum (*Didelphis virginiana*). Feral horses and pigs are also found in Currituck Banks (see section 2.9).

2.9:   Invasive Species

Invasive species are a growing concern for the Currituck Banks Reserve. Several have been documented within the Reserve boundary. Common Reed (*Phragmites australis*) is a nonnative invasive marsh grass growing in Currituck Banks marshes (Figure 2.10). Phragmites tends to grow into a monoculture and crowds out native marsh plants. The habitat value of Phragmites is considered much lower than a native marsh and waterfowl usage is reduced (Roman et al. 1984). Phragmites also tends to alter the soil biochemistry making it unsuitable for native plants (Windham and Lathrop 1999). Phragmites is a rapid grower and can be highly resistant to management techniques. See section 2.11 for information regarding a current research project at Currituck Banks that is studying the effect of Phragmites removal.

Figure 2.10: Phragmites australis (Common Reed) at Currituck Banks.

Currituck Banks and the adjacent Nature Conservancy and Fish and Wildlife properties are home to a feral herd of horses (Figure 2.11). These horses are managed by the Corolla Wild Horse Fund. The Fund has an advisory board made up of the landowners impacted by the horses as well as other stakeholders. The goal of the Fund is to manage the horses for a safe carrying capacity and minimal environmental degradation. A recent population assessment determined that the herd was too large and above the carrying capacity for the resources in the region. Corrective efforts are being explored by the Fund. The impact of the horses on Currituck Banks is largely unknown. This is a gap that needs to be addressed by future research. It is thought that the horses spend most of their time north of the Reserve property. But there have not been any tracking studies to quantify this observation. The need for research into the impact of the horses is further justified by the fact that the areas north of the Reserve are continuing to be developed. This will squeeze the horses into a smaller more fragmented habitat, potentially making the areas within the Reserve more appealing. This could jeopardize the habitats at Currituck Banks because the land and plant species are not appropriate horse habitat.

Figure 2.11: Feral horse at Currituck Banks.

Feral pigs are also found on Currituck Banks and the lands to the north (Figure 2.12). Historically, the pig use was limited to the marshes at the northern end of the Reserve. However, recently the pigs have started rooting within the maritime forest and interdunal areas. This activity could cause extensive tree damage as the shallow roots of the trees are damaged during the pig foraging activities. The pig hoofs as well are not adapted to the soils of the region and tend to sink in and break up plant roots. Both these activities could lead to tree/shrub loss and increased erosion. Hunting for feral pigs is allowed from September through March, although not enough pigs are taken to affect population numbers. Similar to the horses above, as the area north of Currituck Banks is developed the pigs' use of the Reserve is likely to increase. Thus, research into the ecological effects of the pigs is needed for this Reserve.

Figure 2.12: Feral Pig.

2.10: Stressors

The Currituck Banks Reserve is exposed to a variety of stressors, both natural and anthropogenic (man-made). Natural stressors include hurricanes and Nor'Easters, inlet migration/closure, sea level rise, salinity fluctuations and sedimentation. Anthropogenic stressors include altered land use, pollution, nutrient loading, and habitat disruption. Some key anthropogenic stressors are discussed in detail below.

A: Altered Land Use

The type of land cover present is a critical issue because how the land is used and the type of cover on it has large impacts on its ability to sequester nutrients and pollution rather than convey them to surface waters. Natural land covers with vegetative cover such as forest and marsh have large buffering capacities. They tend to trap nutrients and sediment prior to them entering surface waters. Developed land tends to have very little capacity to absorb nutrients and pollution. This is because developed land has increased impervious surfaces such as roofs, roads, and parking lots. These surfaces do not let water infiltrate the ground and high percentages of impervious surfaces have been correlated with degraded water and sediment quality (Holland et al. 2004, Mallin et al. 2000b). Consequently, runoff from these surfaces usually picks up whatever contaminants and nutrients are on them and rapidly moves these materials to surface waters (Mallin et al. 2000b, Mallin et al. 2001).

To assess the amount of change within the Currituck Banks watershed, land cover types were evaluated for the two most recent years that data were available, 1991 and 1997. Land cover information was obtained for coastal North Carolina from NOAA's Coastal Change Analysis Program. Figure 2.13 shows the land use classifications from 1991 and 1997 for the Currituck Banks watershed (United States Geological Survey - Hydrologic Cataloging Unit 030310205). See Appendix 4 for detailed methodology. This delineation covers all the areas of the Pasquotank River Basin as shown in Figure 2.5 except for the Pamlico Sound sub-basin south of Roanoke Island. Equivalent land cover data is not available for the Virginia portion (15%) of the Currituck Banks watershed. The major land cover types were water (31%), Palustrine Forested Wetland (22%), and cultivated (18%).

For clarity the changes that occurred between 1991 and 1997 have been grouped into three categories: 1) decreased vegetation cover (of any type), 2) increased vegetation cover (of any type), and 3) a change from one type of non-vegetated cover to another (neither an increase or decrease of vegetation). The decrease in vegetation cover category includes all areas where the Land Cover changed between 1991 and 1997 to a class that characterizes conditions with generally less plant cover or biomass. Examples of this category are a transition from Forested to Grassland or Scrub-shrub to Low Density Development. The increase in vegetation cover category was assigned to all areas where the Land Cover changed to a class that represents generally greater plant cover or biomass. Examples of this category are succession of grassland to Scrub-Shrub and Scrub-Shrub to Forested. The change in non-vegetated cover category designates all areas that had different non-vegetated land cover classes in 1991 and 1997. Examples included water to unconsolidated shore, unconsolidated shore to bare land and bare land to low-density developed. Figure 2.14 and Table 2.6 show the changes between 1991 and 1997 associated with these three groups.

Changes that occurred between 1991 and 1997 affected 7% of the total land area within the watershed. The difference between vegetation losses and gains were essentially even. The increase in vegetated conditions was mainly associated with succession of Grassland to Scrub/Shrub and Evergreen Forest. The majority of decreased vegetative cover was Evergreen Forest reduced to Grassland and Scrub/Shrub with the largest tract in the northern center area of the watershed. Only 0.6% of the total vegetated land areas were lost to low and high density

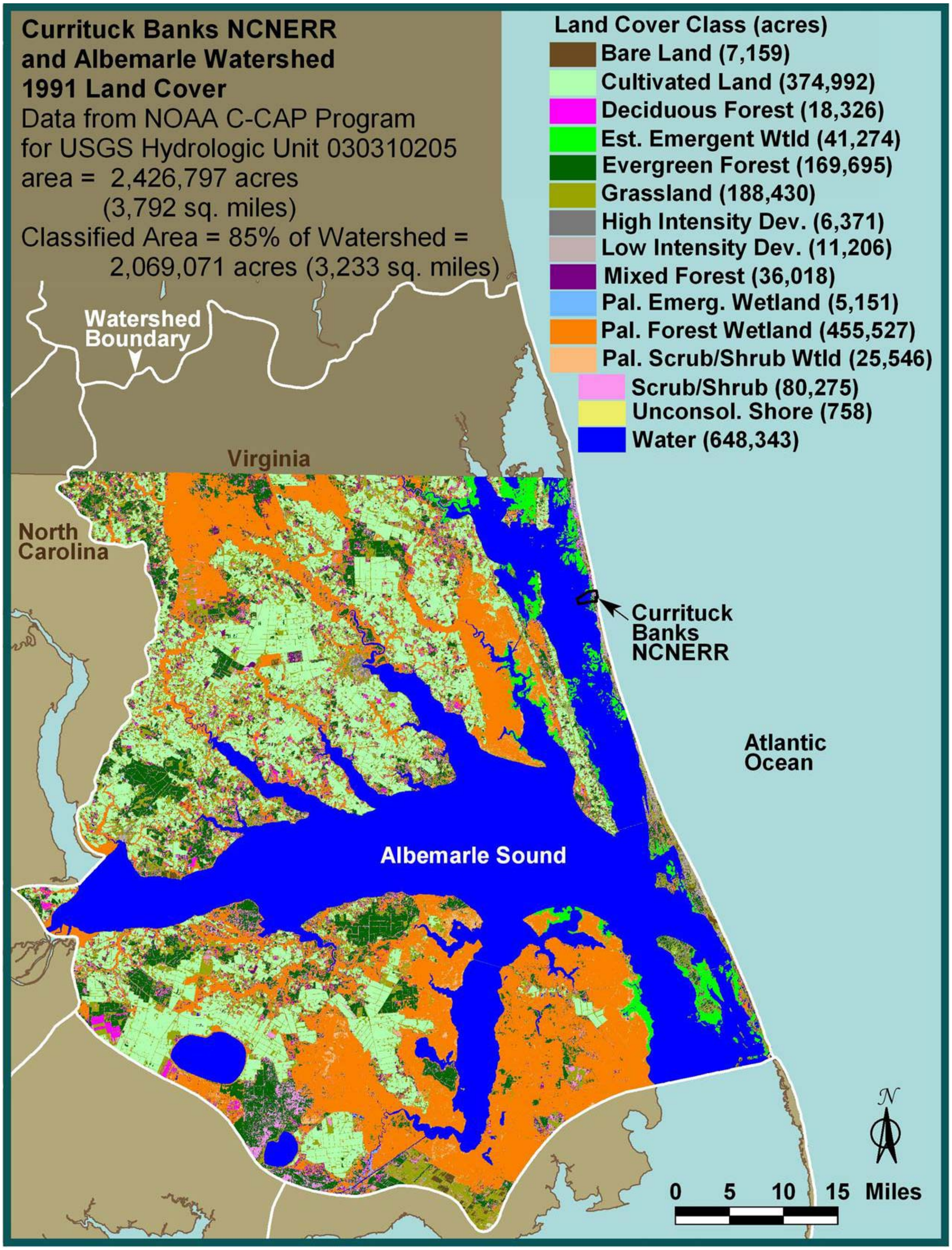


Figure 2.13a: Land use classification from 1991 in the Currituck Banks watershed.

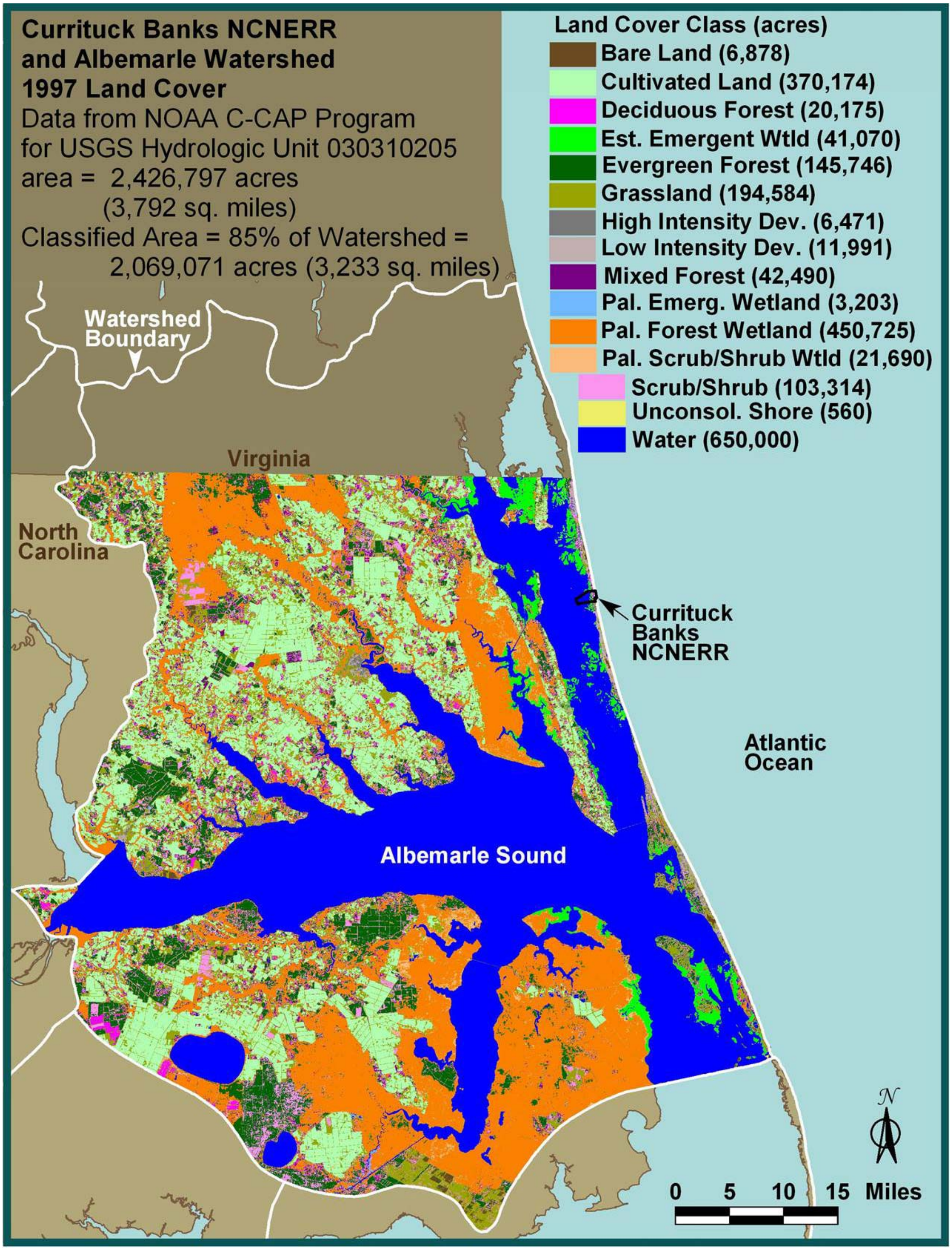


Figure 2.13b: Land use classification from 1997 in the Currituck Banks watershed.

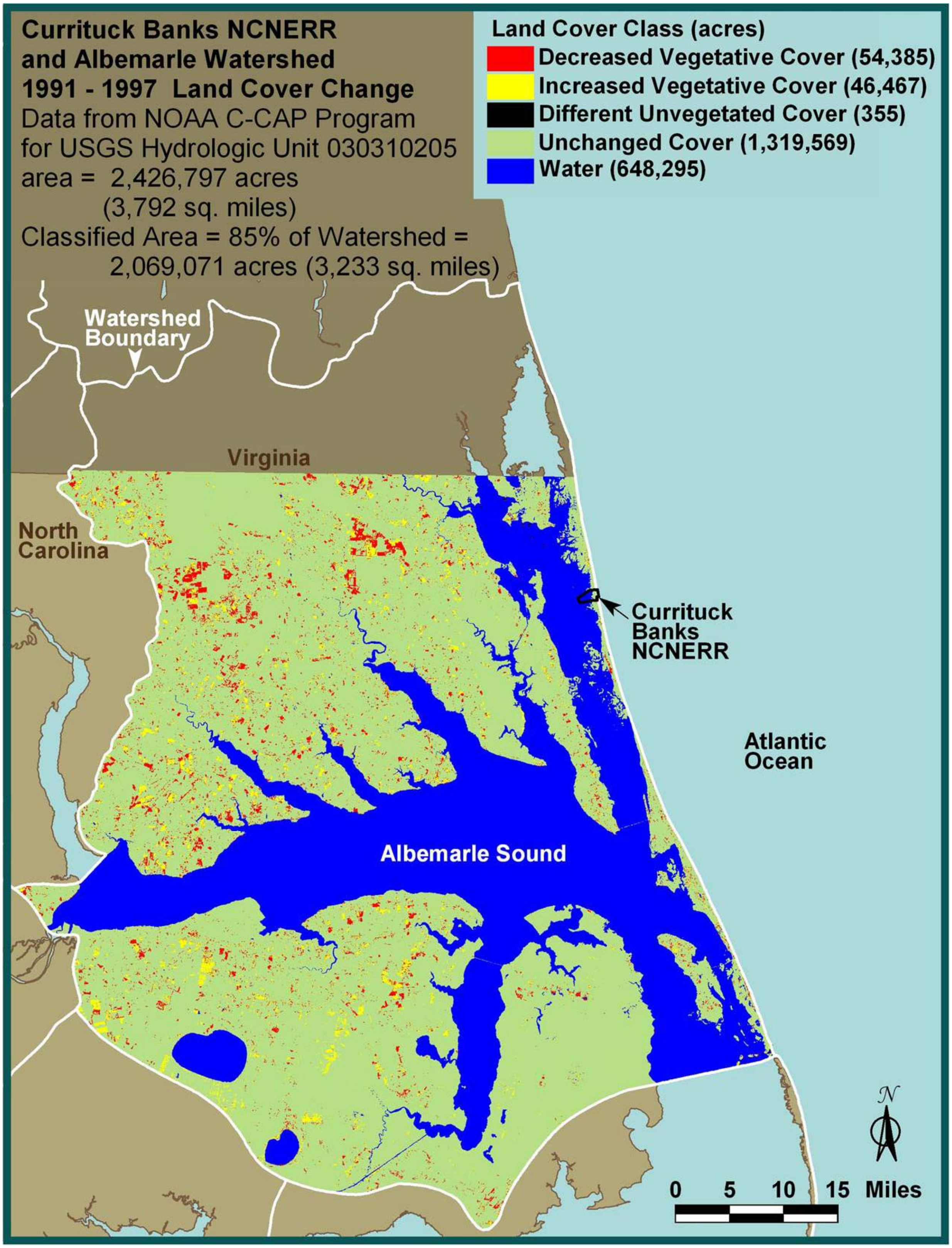


Figure 2.14: Changed land cover from 1991 to 1997 in the Currituck Banks watershed.

development. This suggests that not much buffering capacity was lost in the watershed between 1991 and 1997. Since 1997, development has continued at a rapid pace. These changes are not captured in the analysis here. When the latest land-cover data is released from NOAA, this effort will be repeated. It is anticipated that a large loss of vegetative cover has occurred since 1997.

Table 2.6: Change in land cover from 1991 to 1997 in the Currituck Banks watershed

Category	Acres	% of total
Total mapped area	2,069,071	n/a
Water area	648,295	31.3
Total land area	1,420,776	68.7
Decrease in vegetative cover	54,385	3.8
Increase in vegetative cover	46,467	3.3
Change from one unvegetative cover to another	355	0.02
Unchanged land cover	1,319,569	92.9
Net loss of vegetation = 0.6%		
Percent of land area with changed cover types = 7%		

B: Pollution/eutrophication

Eutrophication leads to excessive phytoplankton production. This can lead to a multitude of water quality problems including hypoxia, decreased light penetration, altered community composition, loss of seagrass beds, and decreased fish and shellfish populations. Recovery from eutrophication can take long periods of time even if the causes of the eutrophication are immediately halted (Nixon 1995; Paerl et al. 1998; Mallin et al. 2000a; Niemi et al. 2004). In Currituck Banks eutrophication has historically not been a big issue. This was mainly because there was not much human presence in the area. As noted in the water quality section, stormwater runoff has become an important source of pollution in the region in recent years. This fact is observable in the ocean side enterococci numbers that occasionally violate the state standards. Loss of SAV in Currituck Sound has also been blamed on reduced water quality (Davis and Brinson 1989), with parameters such as total suspended solids, chlorophyll and nutrient concentrations affecting light availability and suitability of habitat for SAV (Koch 2001). These issues have direct impacts on Currituck Banks. Traditional uses such as swimming and fishing are not possible when the beach is closed due to bacterial contamination. Loss of SAV has caused dramatic changes in the fauna of Currituck Sound including decreased fish and waterfowl.

These trends are expected to worsen in the future as well due to development pressure. Two expected projects have tremendous potential to enhance the rate of development in the region over the next decade. A mid-island bridge is planned that will connect Corolla to the mainland. This would enhance access to the area, making development much more likely. Extending Highway N.C. 12 north through the Reserve toward the Virginia border has also been proposed. This would directly impact the Reserve by separating the Reserve into two halves. Both these projects pave the way for future development around Currituck Banks, thus increasing the potential for more water quality impacts.

C: Public Use

Most visitors using Currituck Banks do so in an appropriate manner. Walking and hunting are the two most common activities within Currituck Banks. The Reserve is typically accessed via the boardwalk and hiking trails. Hunters are asked to use the northern portion of the Reserve, to maintain a safe distance between themselves and other users of the Reserve. These types of activities have a very low impact on the overall health of Currituck Banks.

Unfortunately, the Reserve also receives several types of inappropriate use. These usually occur after hours when staff is not present. The parking lot at the head of the walking trails and boardwalk is heavily utilized. Litter and vandalism are common occurrences. Bike racks and portable rest room facilities that were originally provided at the parking lot had to be removed because of severe abuse. Off road vehicles access the northern portions of the Outer Banks through the beach corridor of Currituck Banks. This impact can disrupt dune communities including sand stabilizing plants, nesting shorebirds and sea turtles. The vehicle traffic is also a major source of hydrocarbon pollution. Vehicle traffic is highest during summer.

2.11: Research Activities

The information in this section is in a rapid state of flux. Research projects are constantly being initiated, executed and completed. As a result, this section will rapidly become dated. Despite this complication, it is still beneficial to describe the current body of research in this manner. The past projects represent a large foundation which future projects can utilize as planning guides. The projects currently being conducted are designed to address current high priority coastal management issues. Thus, in addition to the actual research results, these projects will provide future interested parties with awareness into what the high priority issues were for the Reserve at this time. The needed research represents current knowledge gaps that need to be addressed. While future projects may address some of these, the underlying issues such as eutrophication and sea level rise will still be valid.

A: Research Facilities

The office facilities for the Currituck Banks are located in the town of Kitty Hawk, approximately 35 miles south of the site. There are no laboratory facilities located at this office, although space is available for minimal sample processing. Computer equipment and internet access are available allowing all types of data entry and analysis. Staff and volunteers of NCNERR are able to use the laboratory facilities of the University of North Carolina - Coastal Studies Institute located in Nags Head, N.C. These labs, located about eight miles south of the Kitty Hawk office, are fully equipped and provide the capability to conduct many types of research activities.

In addition to the Coastal Studies Institute, several entities in the Currituck region assist NCNERR with research and stewardship activities. They do this by providing space, logistical support and technical expertise. The U.S. Army Corps of Engineers has a field research station located midway between Currituck Banks and the Kitty Hawk office in Duck, N.C. This facility provides NCNERR with valuable climatic data and access to an oceanic pier if needed. In addition, meeting rooms at this facility are available to NCNERR if needed. The North Carolina

Wildlife Resources Commission Environment Education Center in Corolla, N.C. has also partnered with NCNERR provided boats and staff time in support of projects within Currituck Banks.

B: Historical Research Activities

Since its dedication, not much research has occurred within the boundaries of Currituck Banks. The remoteness of the Reserve is the primary reason for this. There have been a few studies conducted within the northern Outer Banks and the Currituck Sound. These are documented in Appendix 6, the bibliography of work conducted within NCNERR. Topics of these efforts include the sand supply and inlet dynamics for the Currituck spit (Inman and Dolan 1989; Leithold et al. 1991), the salinity of Currituck Sound (Caldwell 2001), wave and climate models (Goldsmith 1977), the sediment characteristics of Currituck County and Sound (Soil Conservation Service 1984), habitat use of feral horses (Rheinhardt and Rheinhardt 1997) and waterfowl and American coot abundance in relation to submersed macrophytic vegetation (Wicker and Endres 1995). Researchers from NOAA's Center for Coastal Environmental Health and Biomolecular Research in Charleston, SC recently completed a project at Currituck Banks examining the sediments in the Reserve using an EPA-Environmental Monitoring and Assessment Program style sampling design. The results of this project showed that the overall condition of the sediments within the Reserve was good and contaminant loads were relatively low (Cooksey and Hyland 2007). The lack of work to date is a problem and informational gap that NCNERR needs to address. This work has already started in earnest. The next section details current research projects going on within Currituck Banks.

C: Current Research Activities

Research projects currently underway at Currituck Banks will help fill the informational gap identified in the previous section. Several projects currently ongoing have sample sites directly within the Reserve boundaries. These projects are designed to examine the impact of atmospheric deposition of nutrients, the impacts to and recovery of native marsh species after removal of *Phragmites australis* via mowing and herbicide application, the amount of SAV coverage in Currituck Sound, and the potential for a toxin producing cyanobacteria to become dominant in Currituck Sound waters. All of these projects will provide critically important information that previously was not available for Currituck Banks.

The atmospheric deposition work is a part of a larger study examining the eutrophication potential of increased atmospheric deposition of nutrients to North Carolina estuaries and sounds. This is extremely important as prior work has shown that atmospheric sources can contribute upwards of 50% of the new nitrogen to coastal oceanic waters (Paerl and Fogel 1994). This work is being conducted in partnership with the U.S. Fish and Wildlife Service, the University of North Carolina – Institute of Marine Science and North Carolina State University. As part of this project NCNERR has been collecting weekly rain water samples from within Currituck Banks (see Figure 2.3). This project has shown that the wet precipitation is a significant source of nutrients for the Reserve, and that the phytoplankton in the region are stimulated by pulses of nutrients. These results clearly show that the area around Currituck Banks is susceptible to eutrophic changes.

The *Phragmites* removal project is a dual purpose experiment. Initially it was a stewardship project solely aimed at removing the Phragmites from Currituck Banks. However through collaboration between the research and stewardship sectors, the project was augmented to also allow NCNERR to monitor the recovery of native marsh species after the *Phragmites australis* was removed. The *Phragmites* stand at Currituck Banks has been growing concentrically over the past two decades. As a result, there are several age classes of the *Phragmites* present (Figure 2.15). Other studies have shown a reduction in biodiversity as many native species are replaced by the more cosmopolitan *Phragmites* species (Chambers et al. 1999). Thus, a long term monitoring program was designed to sample locations within each of these age classes annually. The results of this study will allow NCNERR to make better management decisions regarding *Phragmites* removal.

A visitor use survey was conducted in the summer of 2007. This project was conducted by both NCNERR staff and researchers from UNCW. Data analysis is currently being conducted. This project will allow site managers for Currituck Banks to better understand the public use that the Reserve receives. This will allow more efficient management of the Reserve to maximize public benefit without negatively impacting the natural community.

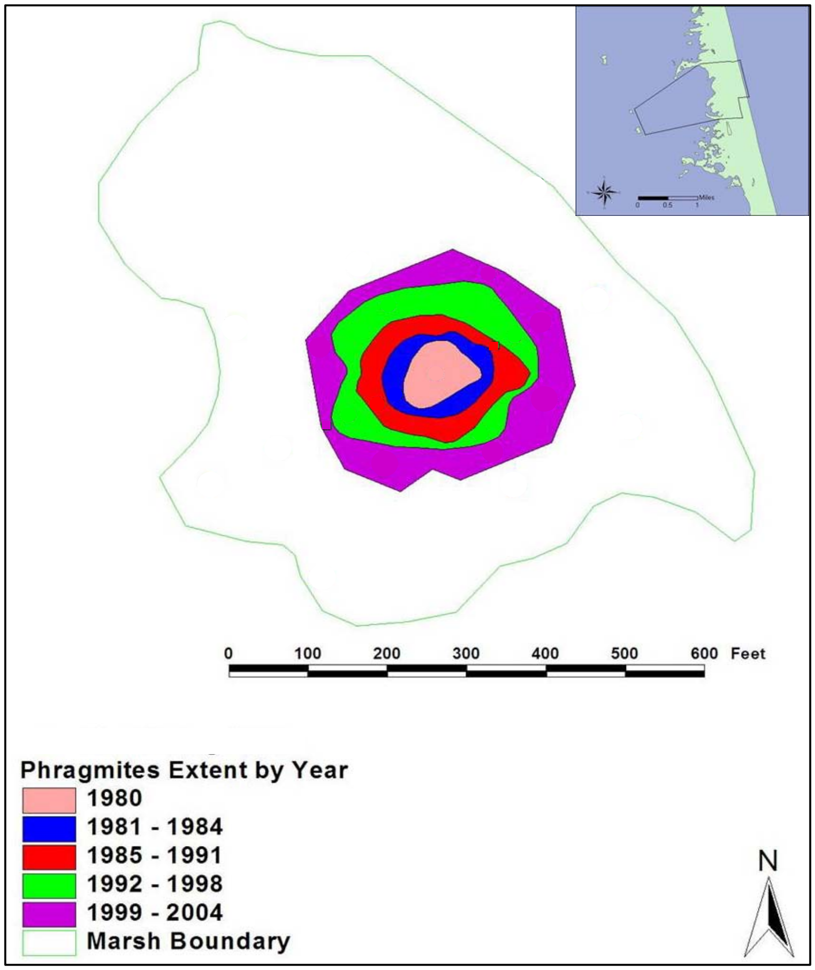


Figure 2.15: Currituck Banks Phragmites australis extent by year. The insert shows the location of the stand in Currituck Banks.

Elizabeth City State University in partnership with United States Fish and Wildlife Service (regions 4 and 5), Virginia Institute of Marine Science, North Carolina Department of Environment and Natural Resources, and the Albemarle-Pamlico National Estuary Program are conducting a study of SAV habitats in Currituck Sound in order to update earlier surveys conducted by Carraway and Priddy (1983), Davis and Brinson (1989), and Ferguson et al. (1989). They are using color aerial photography to digitize locations of SAV. Field verifications have shown the dominant SAV species in the region include Widgeongrass (*Ruppia maritime*), Pondweed (*Potamogeton perfoliatus*), Wild Celery (*Vallisneria Americana*), and Eurasian water-milfoil (*Myriophyllum spicatum*) (Davis and Brinson 1989). Elizabeth City State University has produced a GIS spatial database and maps. These maps (Figure 2.16) provide a baseline against which future changes in SAV spatial coverage can be judged.

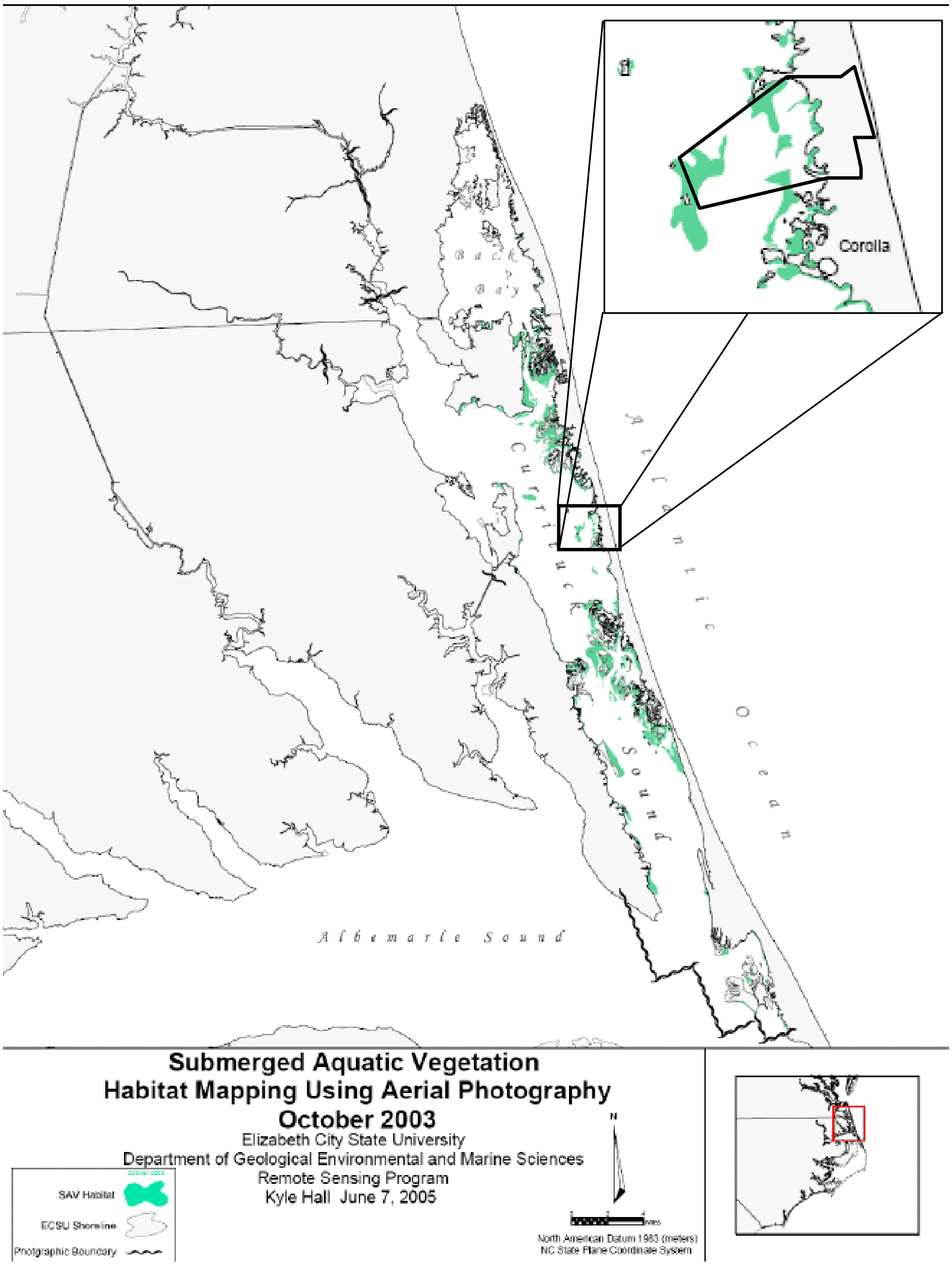


Figure 2.16: Submerged aquatic vegetation spatial coverage in Currituck Sound. Insert shows a close up of the area around Currituck Banks.

This will be a critical factor as work continues to restore the SAV in Currituck Sound.

A GRF project is also currently occurring within Currituck Banks. This is the first time a GRF has worked within the Currituck Banks component of NCNERR. The project is designed to examine the potential for Cylindrospermopsis raciborskii to become problematic within Currituck Sound. This cyanobacteria is a toxin producing cell and can lead to detrimental effects upon both fauna and humans. This research will help inform management schemes designed to protect Currituck Sound. It also will provide NCNERR valuable information regarding the community composition of the phytoplankton within the Reserve.

2.12: Future Research Needs

The above projects are providing valuable information for Currituck Banks, but much work remains to be done. Research into the effect of the feral populations of horses and pigs needs to be completed. The U.S. Fish and Wildlife Service would be an ideal partner to complete this work because they face the same management issues on their property north of Currituck Banks. The North Carolina Wildlife Resources Commission could also be brought in as a partner to help educate the public about the impacts of the horses.

The mapping efforts that have been conducted within Currituck Banks and its associated watershed need to be repeated. Specifics of interest to NCNERR are the loss of vegetative cover within the watershed, the conversion of upland Reserve habitats to marsh, the spatial coverage of SAV within Currituck Sound, and documentation of any new invasive species. Only by repeating these mapping efforts will changes be able to be quantified.

Partnership with the N.C. Wildlife Resources Commission is a great possibility with their Education Center in such close proximity. The N.C. Wildlife Resources Commission emphasizes education on wildlife in the surrounding area. With their expertise, it would be of interest to gather detailed data on wildlife in and around Currituck Banks. An initial idea has been offered from N.C. Wildlife Resources Commission to conduct amphibian research and counts, information which the Reserve lacks. Since amphibians are considered keystone species, this information would be invaluable as a predictor for climate change in the Currituck Banks area. Documenting the wildlife would also allow fauna invasive species to be documented.

Continuing SWMP-like monitoring of water quality in Currituck Sound is a high priority research need. The oligohaline back barrier sound system is a unique habitat not found anywhere else in the State. This, coupled with the expected development pressure, and the large group of data users including researchers, state managers, and the general public, makes documenting the changes in water quality within Currituck Sound paramount. Potential partners to help with this project include the Albemarle Pamlico National Estuary Program, Elizabeth City State University and the University of North Carolina - Coastal Studies Institute, and the N.C. Division of Water Quality.

Marsh elevation studies also need to be conducted within Currituck Banks. One of the big issues for the mainland side of Currituck Sound is sea level rise. Much of the area is very low relief and quite susceptible to sea level rise. Since there is not any development within the Reserve and natural processes are allowed to occur, the data from Currituck Banks could serve as the ideal control to compare other areas against. Ideal partners to assist with this project include the United States Geological Survey, and NOAA – National Centers for Coastal Ocean Science.

Chapter 3:   Rachel Carson Component

3.1:   Environmental Setting

The Rachel Carson component of the NCNERR is located in the central part of North Carolina's coast. It is located near the mouth of the Newport River in southern Carteret County, directly across Taylor's Creek from the historic town of Beaufort. One of the two State ports, Morehead City, is located three miles to the west. Rachel Carson is bounded to the north by Taylor's Creek and the city of Beaufort, to the east by Back Sound, to the south by the Cape Lookout National Seashore, and to the west by Piver's and Radio Islands (Figure 3.1). The Rachel Carson Reserve is located in the White Oak River Basin and on a broader scale in the Carolinian biogeographical province. Acquisition of the area was completed in 1985, with the addition of Middle Marshes later in 1989. The site is accessible only by boat. The state Wildlife Resources Commission operates a public boat ramp and parking lot along Taylor's Creek, while the Duke University Marine Laboratory and NOAA's Center for Coastal Fisheries and Habitat Research Laboratory have boat-launching facilities on nearby Pivers Island. Several private ferry companies offer access to the Reserve from Beaufort. The 2,625-acre (10.6 km^2) site consists of several small islands (Carrot, Town Marsh, Bird Shoal, Horse Island, and Middle Marshes) and extensive salt marshes and intertidal/subtidal flats (Taggart and Henderson 1988) (Figure 3.1).

3.2:   Historical Uses

A: Native American Uses

Prior to European colonization of North Carolina, the Carrot Island-Middle Marshes area may have seen intermittent use by the Coree tribe of Native Americans. The Corees are thought to have spent considerable time on the nearby Outer Banks especially in the vicinity of Cape Lookout (Taggart and Henderson 1988)

B: Colonial Uses

European settlement of the Beaufort area began in the first two decades of the eighteenth century. In 1723 the commissioners of Beaufort began to sell lots as the town developed as a port. The early settlers used the waters in and near the Rachel Carson site for shipping lumber, naval stores, and farm commodities (Taggart and Henderson 1988).

During the early 1700s, several pirates were active along the North Carolina coast. One in particular, Edward Teach (Blackbeard) sailed the waters of the Caribbean and eastern U.S. Coast. (Lee 1974; Hill et al. 1975). In 1718 Blackbeard's flagship the Queen Anne's Revenge, struck a shoal just off Beaufort Inlet and was lost. The suspected remains of his ship were found less than 4 miles (6.4 km) from the Rachel Carson Reserve in 1996 by Intersail, Inc. Since 1996, several marine archeological expeditions have been conducted on the wreck to scientifically document the wreck and recover and preserve artifacts (North Carolina Department of Cultural Resources 2006).

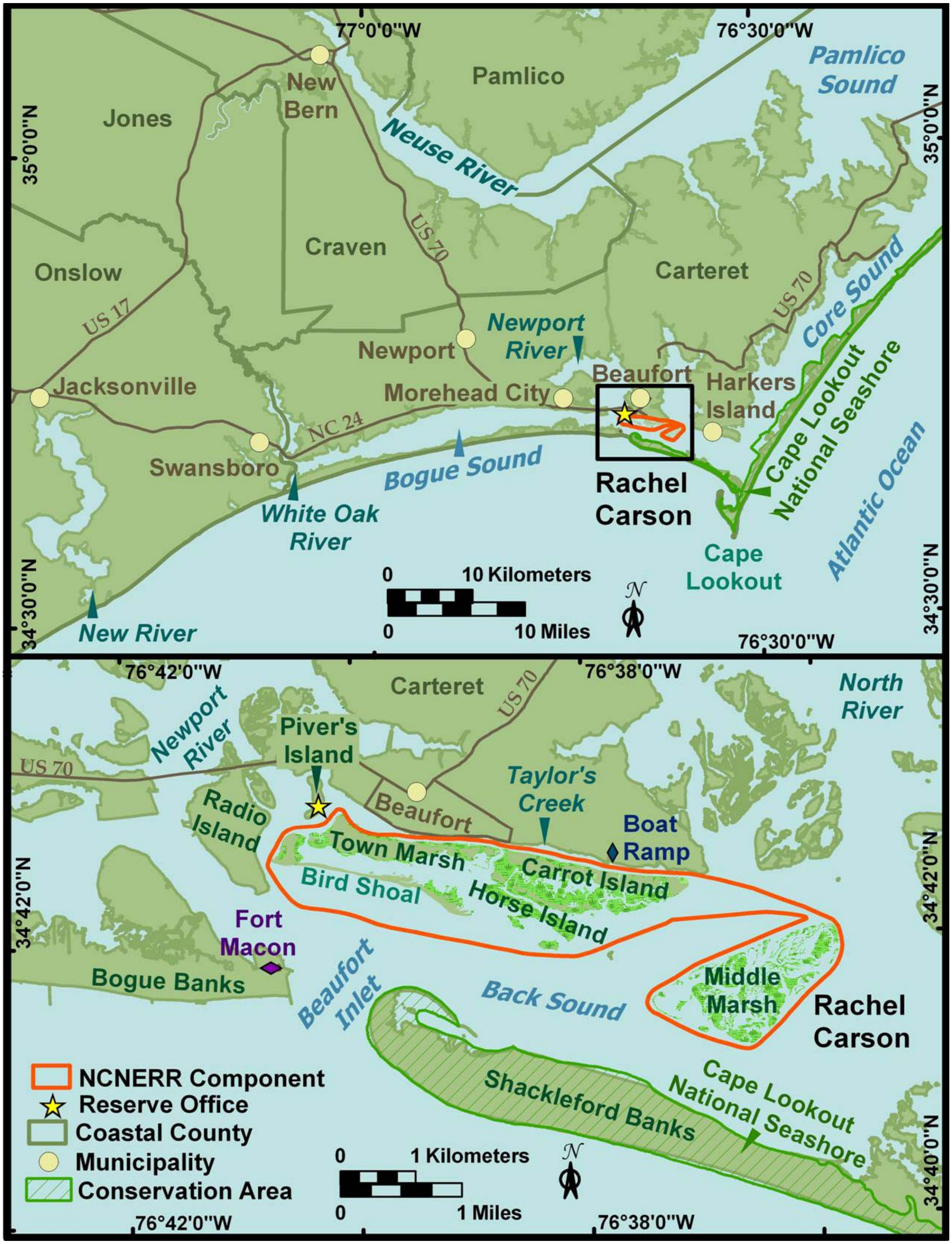


Figure 3.1: Rachel Carson location. The bottom panel shows a close up of the Rachel Carson Reserve component including local names for areas of the Reserve.

C: War Uses

In 1782, a Revolutionary War skirmish near the mouth of Taylor's Creek involved townsmen and a small British-landing party. Following an initial exchange of fire, the British moved about one-half mile (0.8 km) eastward and landed on Carrot Island, spending the night there. At sunrise, the British crossed Taylor's Creek to the mainland, overcame the local troops, and swept into Beaufort to begin a short-lived occupation of the town (Taggart and Henderson 1988).

Although not directly occurring on the Reserve, there was significant Civil War activity within 5 miles of the present day Reserve. At the start of the Civil War, Union forces were driven from Fort Macon. Fort Macon was an earthen and brick walled coastal defense built after the war of 1812 to protect Beaufort inlet (Figure 3.1). Confederate forces used the guns of Fort Macon to protect the deep water port of Beaufort so that supplies needed to sustain the confederate war effort could be brought in. In 1862, Union forces laid siege to the fort in an effort to retake it. After a full day of shelling from land and sea, the fort fell and the Union army re-took control of the fort and Beaufort inlet. The Union army used the fort for the rest of the war to prevent Confederate blockade runners from entering Beaufort harbor and as a coaling station for Union ships. Fort Macon was again used during World War II as a base for an Army coastal defense detachment. The Fort is now part of the Fort Macon State Park and is heavily visited during the warm summer months.

D: Other Historical Uses

As early as 1806, it was reported that mullet were being caught by a fishery on Carrot Island, then dressed, salted and taken to Beaufort to be sold. Other fisheries also developed in the region including menhaden, oysters, clams, flounder, and sea turtles. The first processing plant in the state for menhaden, still a valuable commercial species, was established on nearby Harker's Island in 1865. The first factory in Beaufort was built in 1881. Beaufort began to decline as a port following the establishment of Morehead City in the 1850s. Improvements in the channel from Beaufort Inlet to the Terminal facilities at Morehead City, especially those that have taken place during the twentieth century, completed this eclipse (Taggart and Henderson 1988).

In 1854, Town Marsh (then called Bird Shoal) was three-eighths of a mile long. By 1885, Town Marsh had more than doubled in length and its northern shoreline moved even closer to the Beaufort waterfront. The growth of Town Marsh had made the Taylor's Creek channel almost unusable, so in 1893 the citizens of Beaufort asked the federal government to build a breakwater on Town Marsh to protect the channel along the town's waterfront. Although that request was denied, in the early 1900s the U.S. Army Corp of Engineers began dredging the mouth of Taylor's Creek, using Carrot Island as a dredge material deposition area. Before the dredging, Carrot Island was essentially all tidal marsh with some elevated hammock land.

By the 1930s, the islands had been built up by the dredge material deposition to the point that they provided protection for the town of Beaufort from high winds, flooding and storm waves. In fact, the great hurricane of 1933 caused relatively little damage to the town. The Corps of Engineers continued to utilize the islands as deposition sites for local dredging projects and maintain rights for this purpose even today.

Horses were placed on the island during the 1940s by a Beaufort resident. It was practice then to bring livestock over to the islands to graze. With the resident's passing, the horses remained and became feral. The horses became the property of the State of North Carolina when the land was purchased in the 1980s and are managed as a wild population. The population is currently around 42.

The calm waters of Taylor's Creek behind the Reserve have been a safe harbor for boats since the Army Corp of Engineers finished the first dredging projects in the 1930s. As a result, boaters visiting the Beaufort area utilize the area on the back side of the Reserve as an anchorage.

3.3: Climate

The National Weather Service in Newport, North Carolina provides the most up to date, reliable weather data for the region. The annual maximum temperature for the area is 72.2 °F (22.3 °C), and the minimum is 54.3 °F (12.39 °C). Average total precipitation is 55.56 inches (141.1 cm), with an average snowfall of 1.3 inches (3.3 cm).

Table 3.1: Climate data for Morehead City, N.C. 5/2/1948 to 12/31/2005

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum	55.4/ 13.0	57.4/ 14.1	63.0/ 17.2	70.8/ 21.5	77.8/ 25.4	83.8/ 28.8	87.0/ 30.5	86.7/ 30.4	83.1/ 28.4	75.3/ 24.1	67.0/ 19.4	58.5/ 14.7	72.2/ 22.3
Average Minimum	36.2/ 2.4	37.7/ 3.2	43.3/ 6.3	51.8/ 10.9	60.8/ 16.0	68.6/ 20.4	72.7/ 22.6	71.8/ 22.1	66.9/ 19.4	56.4/ 13.6	46.6/ 8.1	38.8/ 3.7	54.3/ 12.4
Average Precipitation	4.3/ 11.0	3.9/ 9.9	4.0/ 10.3	3.0/ 7.7	4.4/ 11.3	4.5/ 11.5	6.4/ 16.2	6.9/ 17.6	6.1/ 15.5	4.2/ 10.6	3.7/ 9.5	4.0/ 10.1	55.6/ 141.1
Average Snowfall	0.3/ 0.8	0.6/ 1.5	0.4/ 1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1/ 0.3	1.3/ 3.3
Data from NOAA - National Climatic Data Center.													

The Rachel Carson area is especially susceptible to tropical storm/hurricane impacts because of the geography of the region. This part of the coast juts out into the Atlantic Ocean in an east-west orientation (Figure 3.1). Thus, the area is very prone to impact by northward moving storms. Table 3.2 lists all tropical activity that has passed within 65 nautical miles of the Rachel Carson Reserve since 1960. Recently, several significant storms have impacted the area causing heavy damage and flooding including: Hurricanes Bertha and Fran during the summer of 1996, Bonnie in 1998, Floyd in 1999, Isabel in 2003 and Ophelia in 2005.

Table 3.2: Tropical storms passing within 65 nautical miles of Rachel Carson since 1960

Storm	Date	Name	Wind (kts)	Minimum Pressure (mb)	Classification
1	July 1960	Brenda	50	-	Tropical storm
2	September 1960	Donna	95	958	Category 2 hurricane
3	August 1962	Alma	45	1002	Tropical storm
4	September 1964	Dora	45	-	Tropical storm
5	October 1964	Isbell	65	994	Category 1 hurricane
6	October 1964	Isbell	40	1000	Extratropical
7	June 1966	Alma	40	-	Tropical storm
8	June 1966	Alma	40	990	Tropical storm
9	September 1967	Doria	45	-	Tropical storm
10	June 1968	Abby	25	-	Tropical depression
11	October 1968	Gladys	75	-	Category 1 hurricane
12	August 1970	Not named	30	-	Tropical depression
13	August 1971	Doria	50	998	Tropical storm
14	September 1971	Ginger	80	985	Category 1 hurricane
15	October 1971	Ginger	60	991	Tropical storm
16	June 1972	Agnes	30	990	Tropical depression
17	June 1975	Amy	25	1011	Tropical depression
18	October 1975	Hallie	45	1002	Tropical storm
19	September 1977	Clara	25	1012	Tropical depression
20	July 1979	Bob	20	1012	Tropical depression
21	August 1981	Dennis	50	999	Tropical storm
22	June 1982	Subtop 1	60	992	Subtropical storm
23	September 1984	Diana	115	949	Category 4 hurricane
24	September 1985	Gloria	90	942	Category 2 hurricane
25	November 1985	Kate	45	996	Tropical storm
26	August 1986	Charley	55	995	Tropical storm
27	August 1987	Arlene	10	1016	Tropical low
28	June 1995	Allison	40	995	Extratropical
29	June 1996	Arthur	40	1005	Tropical storm
30	July 1996	Bertha	90	974	Category 2 hurricane
31	September 1996	Fran	100	985	Category 3 hurricane
32	October 1996	Josephine	45	988	Extratropical
33	August 1998	Bonnie	95	963	Category 2 hurricane
34	September 1999	Dennis	55	986	Tropical storm
35	September 1999	Floyd	90	956	Category 2 hurricane
36	October 1999	Irene	80	976	Category 1 hurricane
37	June 2001	Allison	25	1006	Subtropical depression
38	July 2002	Arthur	30	1009	Tropical depression
39	October 2002	Kyle	30	1012	Tropical depression
40	September 2003	Isabel	90	956	Category 2 hurricane
41	August 2004	Alex	70	983	Category 1 hurricane
42	August 2004	Bonnie	25	1008	Tropical depression
43	August 2004	Charley	60	1000	Tropical storm
44	September 2005	Ophelia	75	979	Category 1 hurricane

Data from the NOAA – Coastal Services Center.

3.4: Geological Processes

Carteret County is located in the south-central part of the North Carolina coastal plain. In general, the county's land surface is a plain representing a former sea floor that has been elevated above sea level in the relatively recent geologic past. The existing plain slopes toward the Atlantic Ocean at an overall rate of less than three feet per mile, and the topography is flat and largely swampy. The sea has gradually returned to cover much of the low ground in the coastal bays and extends up the streams to form broad estuaries. Wave and tidal action have built up a chain of offshore bars or banks which border the ocean and are separated from the remainder of the county by Bogue, Back, and Core Sounds. The main estuaries with influence on the Rachel Carson component are the Newport and North River estuaries. (N.C. Division of Water Quality 2007)

The islands and tidal flats comprising Rachel Carson consist of Recent and Pleistocene (1.8 million to 10,000 years ago) sediments of the Pamlico Terrace. Soils found within the component generally consist of sandy profiles with little to no horizon development (i.e., Entisol order). This is indicative of soils having a relatively recent origin (Buol et al. 1980). Unlike the other components that make up NCNERR, Rachel Carson is not a true barrier island. The Reserve is located behind the line of primary barrier islands (Figure 3.1).

During the early 1930’s the U.S. Army Corps of Engineers began dredging Taylor’s Creek. The spoil from this deepening project was placed on top of the shoals and marshes adjacent to the creek. These activities raised the elevation of the marshes several feet and are the basis for the present day Town Marsh (which is in actuality an upland island) and Carrot Island. Thus, the upland areas of Rachel Carson are made from sediment dredged up out of Taylor’s Creek. These areas are mostly sand with occasional areas of shell debris. The Army Corps still uses portions of the Reserve as a deposition site for spoils from maintenance dredging activities of Taylor’s Creek.

3.5: Hydrology and Water Quality

A: Hydrology

The waters around Rachel Carson are generally less than six ft (1.8 m) in depth except for Taylor's Creek that is periodically dredged by the U.S. Army Corps of Engineers to a depth of 14 ft (4 m). Tides in the Rachel Carson area average 1.5 ft (0.5 m) and are semidiurnal in nature. The Rachel Carson Reserve is located in the White Oak River Basin (Figure 3.2).
The Reserve is located in the convergence zone of several bodies of water: the Newport River, North River, Back Sound, and Bogue Sound (Figure 3.1). Currents in the region are highly influenced by the adjacent Beaufort Inlet. Beaufort Inlet is dredged in support of the State Port

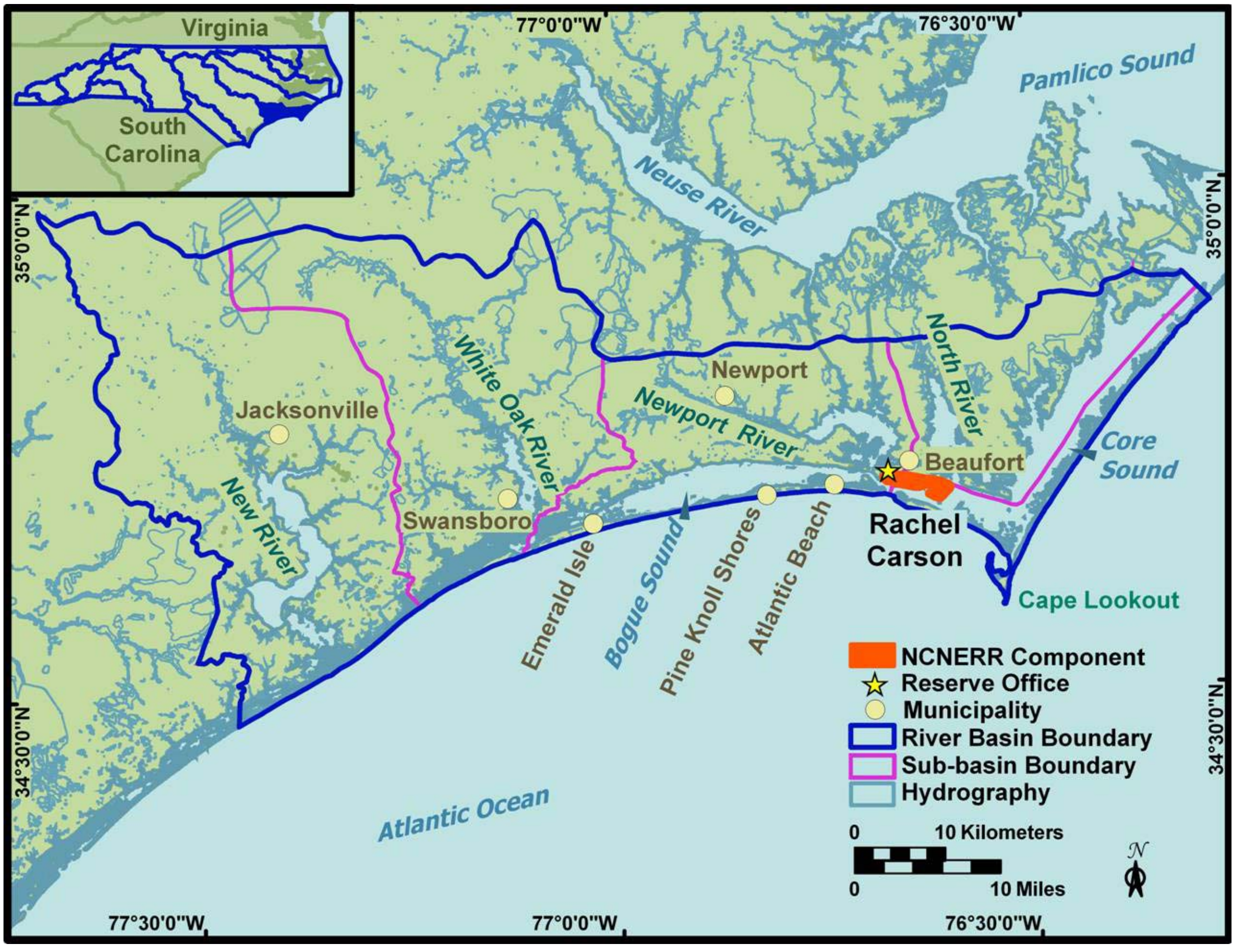
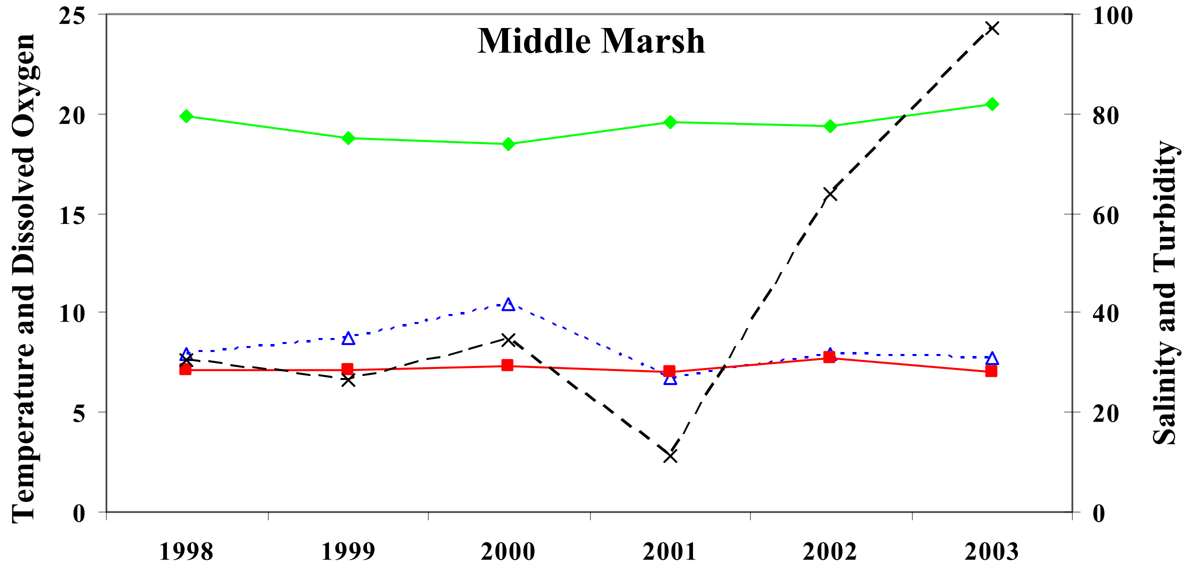


Figure 3.2: White Oak River Basin map.

Facility located in Morehead City to a depth greater than 40 ft (~12 m). This alteration enhances ocean-estuary exchange compared to what would occur if the inlet were not modified. The enhanced exchange increases the pollution capacity of the area waters as pollutants can rapidly dilute into the coastal ocean. The enhanced exchange also means salinity values in the Rachel Carson Reserve are near ocean concentration, ~35 ppt. Figure 3.3 shows yearly averaged water quality data from SWMP-like instrumentation that was deployed by NCNERR from 1998-2003 in the Reserve at Middle Marsh and from Deep Creek from 1999-2003. The salinity values at both sampling locations were very stable and remained near 30 ppt in all years.

The Newport and North Rivers account for most of the riverine influence to the Reserve. The Newport River widens into the Newport River estuary, which separates Bogue Sound from Back Sound. The head of the estuary, near Newport, has periodic, naturally low dissolved oxygen concentrations and low pH values due to swamp water inflow (North Carolina Division of Water Quality 2007). The swamp stream headwaters of the Newport River are relatively pristine and drain portions of Croatan National Forest. The North River is east of the Newport River and drains into Back Sound. The North River drains primarily agricultural land and low development residential areas (North Carolina Division of Water Quality 2007).



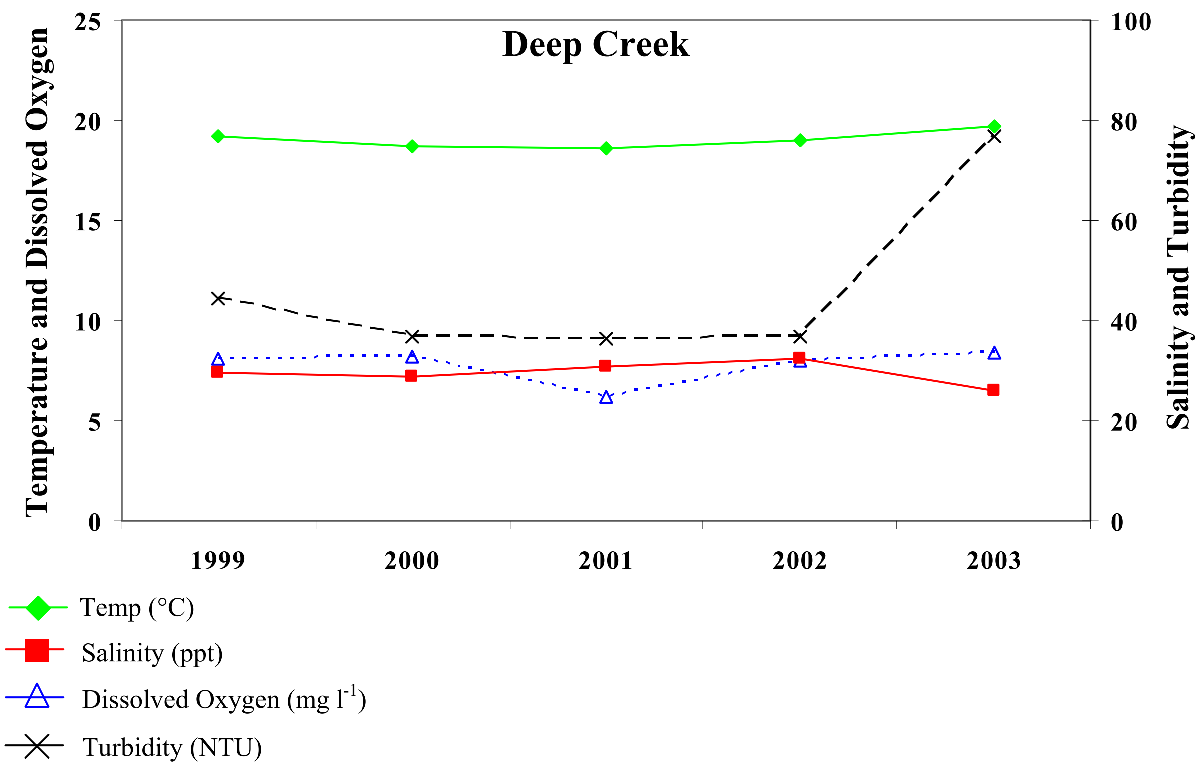


Figure 3.3: Yearly averaged data from the SWMP-like monitoring stations at Rachel Carson.

B: Water Quality

Water quality around Rachel Carson is generally high, with low nutrients and bacteria concentrations and with ample dissolved oxygen (N.C. Division of Water Quality 2007). The yearly data from the NCNERR SWMP-like water quality monitoring stations corroborate this assessment. Yearly oxygen concentrations remained above 6 mg l^{-1} which is well above the level of oxygen required by most estuarine organisms (Diaz and Rosenberg 1995; Sagasti et al. 2001) (Figure 3.3). The low dissolved oxygen signal from the swamp headwaters of the Newport River is completely muted by the time the water gets to the Rachel Carson Reserve.

The largest point source discharge impact to the Rachel Carson Reserve is the Beaufort waste water treatment plant (1.5 million gallons (5,678,117 L) per day) (North Carolina Division of Water Quality 2007). The outfall pipe discharges into Taylor's Creek near the former NCNERR Deep Creek sampling location (Figure 3.4). Because of this outfall, the waters of Taylor's Creek are permanently closed to shellfishing. Water quality of Taylor's Creek and the tidal creeks that enter the Reserve from Taylor's Creek are classified as "SC" (no taking of shellfish and no swimming allowed) by the Division of Water Quality, all other areas in the Reserve are classified as "SA" (safe for shellfish gathering and swimming) waters.

The waters around Rachel Carson are heavily utilized for boating, fishing, swimming, and shellfishing. Consequently, there is a large amount of effort put into quantifying the water quality in the region. The N.C. Recreational Water Quality Program began testing coastal waters in 1997. The mission is to protect the public health by monitoring the quality of coastal recreational waters and notifying the public when bacteriological standards for safe bodily contact are exceeded. They test for enterococcus bacteria (an indicator organism whose presence is correlated with that of others that can cause illness in humans) to determine if swimming advisories should be posted. Limits for enterococcus are based on the level of use a particular beach receives. A Tier 1 area is defined as receiving daily use during swimming season (April – September). Tier 1 beaches shall not exceed either: (1) A geometric mean of 35 enterococci per 100 ml of water, that includes a minimum of at least five samples collected within 30 days; or (2) A single sample of 104 enterococci per 100 ml of water. A Tier 2 area is defined as receiving on average three days of use per week during swimming season. The enterococcus level in a Tier 2 swimming area shall not exceed a single sample of 276 enterococci per 100 ml of water. A Tier 3 area is defined as receiving four days of use per month during swimming season. The enterococcus level in a Tier 3 swimming area shall not exceed two consecutive samples of 500 enterococci per 100 ml of water. There are several Tier 1, 2, and 3 water quality stations located near the Rachel Carson Reserve (Figure 3.4). The data from these sampling locations is presented in Table 3.3 and Figure 3.5.

Table 3.3: Enterococci data for the sampling stations near Rachel Carson 2003-2006

Station	C-2	C-57	C-59A	C-58	C-60A	C-56	C-55B	C-56A
Tier	Tier 1	Tier 1	Tier 2	Tier 2	Tier 2	Tier 2	Tier 2	Tier 3
Minimum	9	9	9	9	9	9	9	9
Maximum	104.4	2006	20	20	20	2006	164	2005
Average	11.6	55.5	9.3	9.3	9.3	72.5	15.0	80.1
Data from: http://www.deh.enr.state.nc.us/shellfish/Water_Monitoring/RWQweb/data.htm								

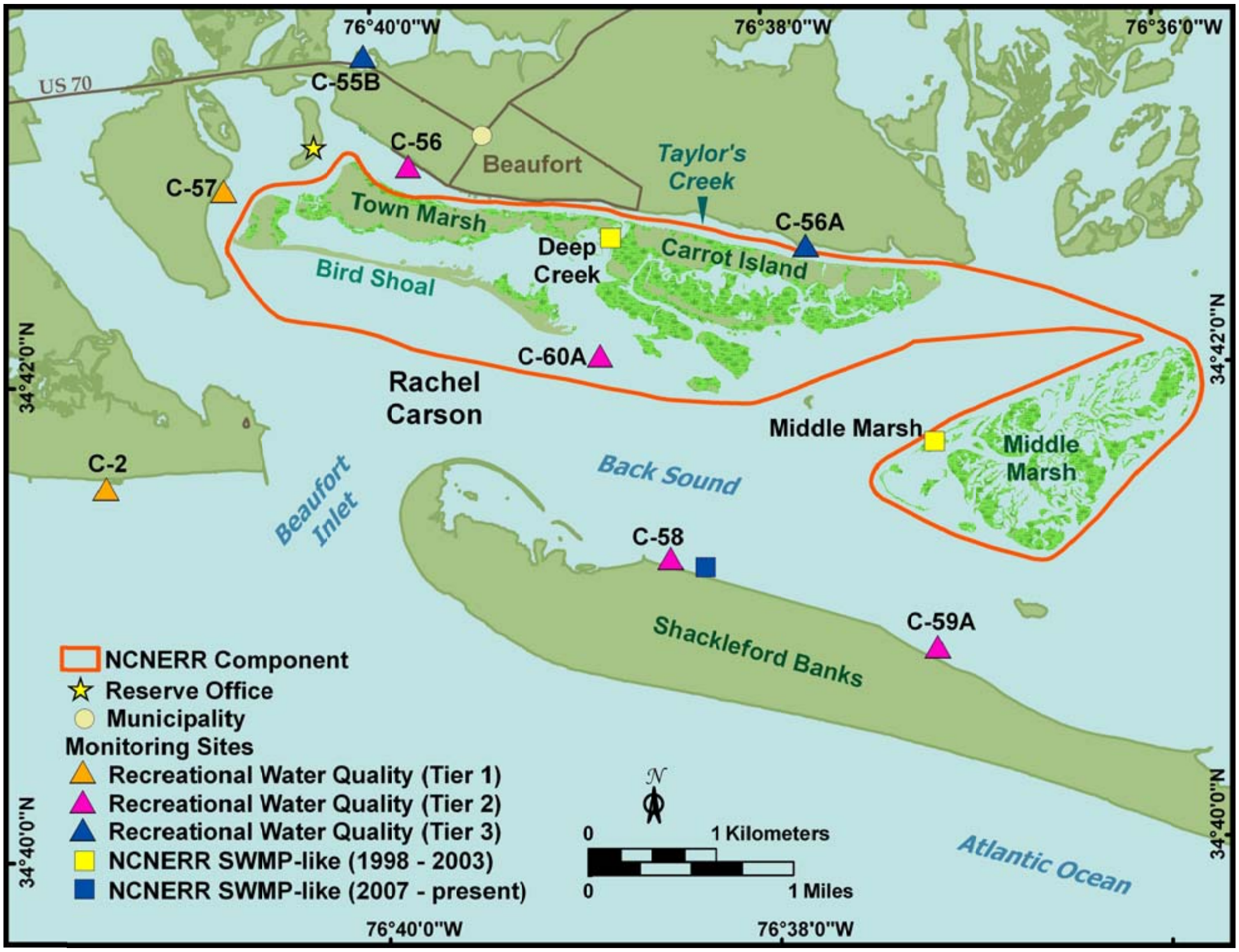


Figure 3.4: Water quality monitoring locations at Rachel Carson.

From these data it can be seen that quite a large variation in the enterococci concentrations exist among the various sampling locations. The sampling sites in Back Sound adjacent to Shackleford Banks (C-58 and C-59A) and the ocean-side boundary of Rachel Carson (C-60A) consistently had the lowest enterococci values. The sampling locations in Taylor's Creek C-56 and C-56A had the highest enterococci values. This contamination could be coming from several sources. The first is the Beaufort wastewater treatment outfall, the second is the public boat anchorage and marinas in the area, and the third is from runoff from adjacent land areas. Regardless of the source, the data show that Taylor's Creek is susceptible to bacteria contamination, and that the shellfish closure in the area is justified.

Unlike the other Reserve components, there has not been any historical nutrient sampling conducted by NCNERR within the Rachel Carson component. This is a data gap for this Reserve component. To address this need and to fill the void in water quality sampling that has existed since 2003, NCNERR has entered into a partnership with the National Park Service. This partnership, codified with a Memorandum of Understanding, provides for two SWMP-like water quality monitoring locations including nutrient sampling. The first of these stations, located within the Cape Lookout National Seashore boundary at the Shackleford Banks boat dock, was installed in October 2007 (Figure 3.4). The second is planned for installation in

February 2008 within the NCNERR boundary at the original NCNERR Middle Marsh SWMP-like sampling location that occurred from 1998-2003 (Figure 3.4).

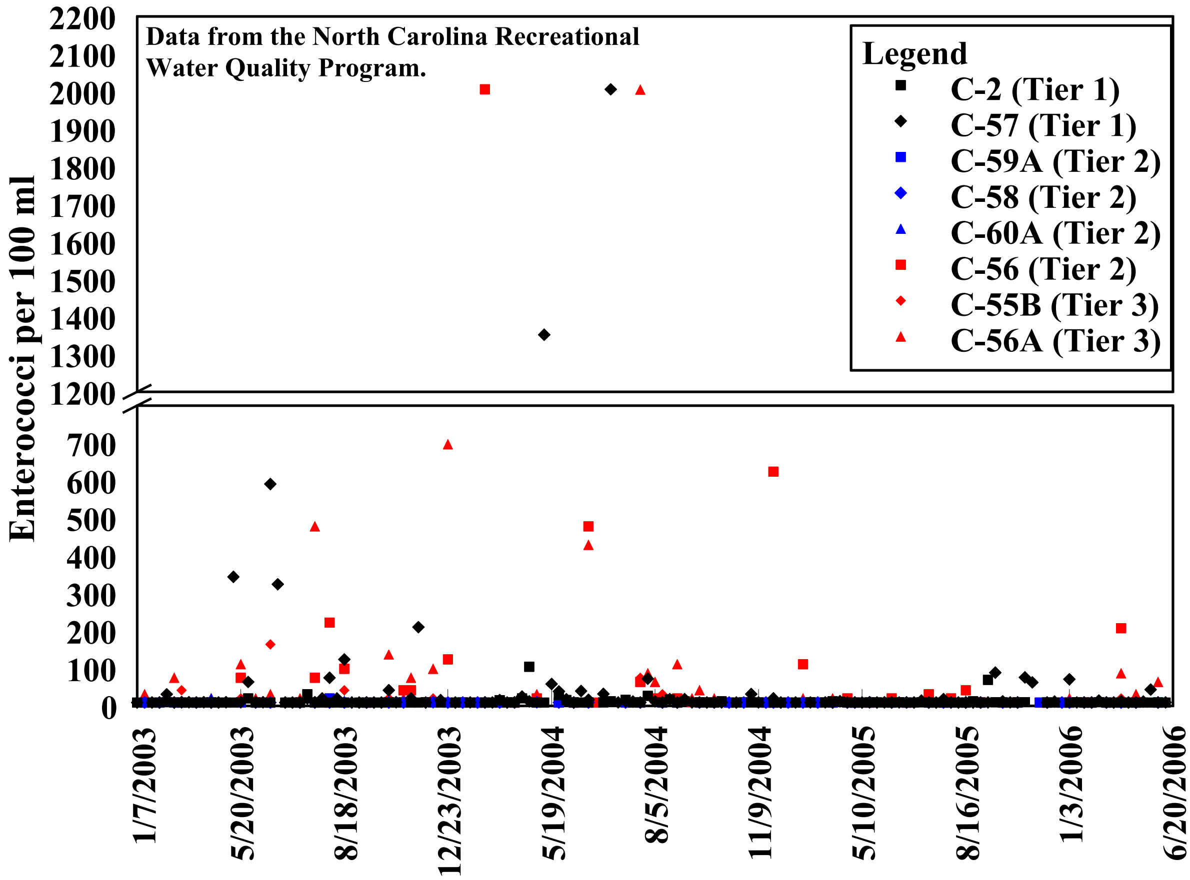


Figure 3.5: Enteroccoci data from the recreational water quality sampling stations near Rachel Carson.

3.6:   Habitat Types

A primary objective of SWMP Phase 3 is to evaluate changes over time in estuarine habitats and coastal land cover. To accomplish this, the types and locations of habitats within the Reserve must be periodically quantified. The habitat types of Rachel Carson were initially characterized in 1994. This effort used a very general classification system that only broke habitats down into very broad categories. These habitat types included subtidal flats, tidal creeks, submerged aquatic vegetation beds, salt marshes, dredge spoil areas, Maritime shrub thicket and forest, dunes and beaches (Table 3.4). Figure 3.6 shows the resultant map from this effort.

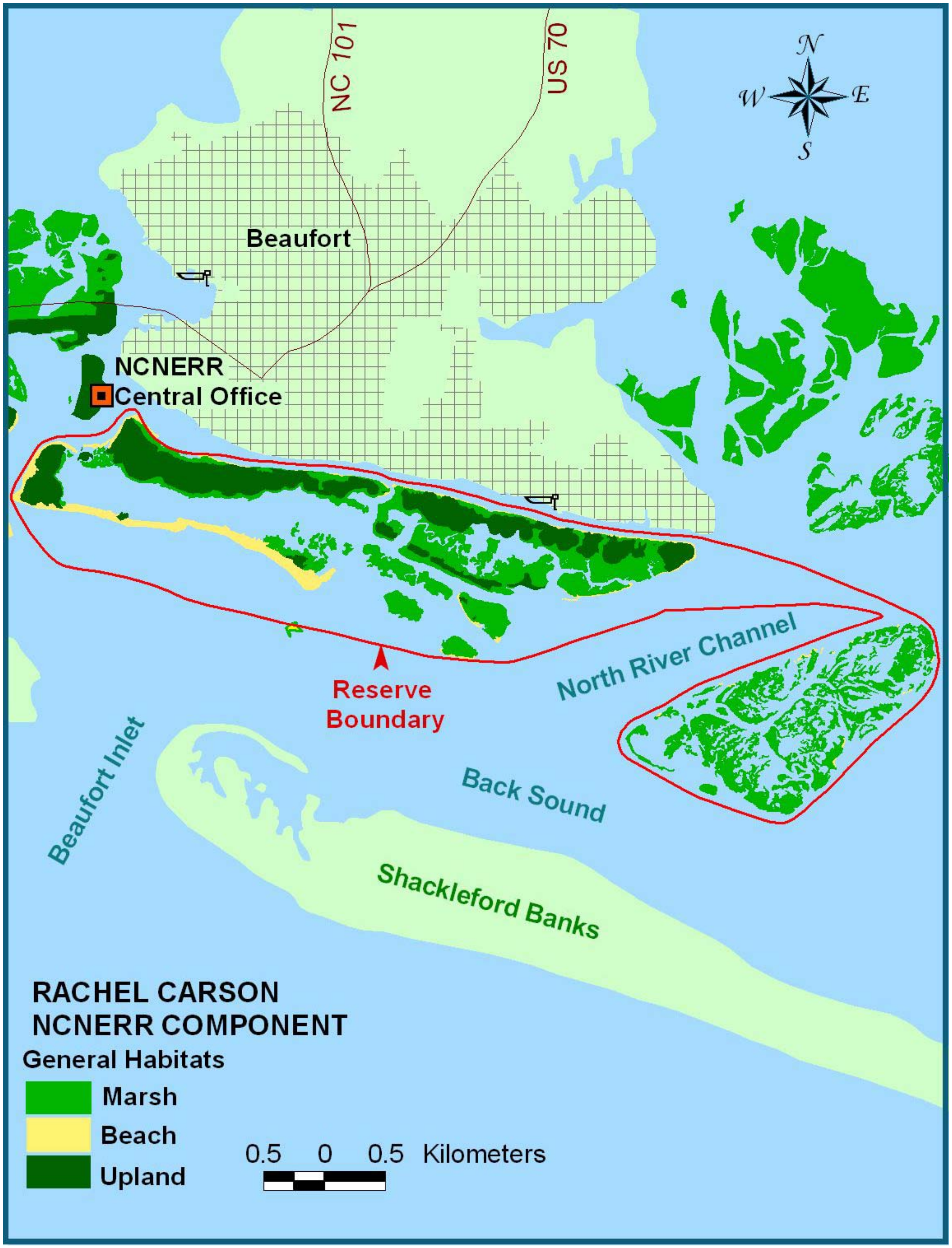


Figure 3.6: Habitat map from 1994 for Rachel Carson.

Table 3.4: Rachel Carson 1994 habitat classifications

Habitat	Description
Subtidal flats	Open sand or mud flats that never get exposed at low tide.
Tidal creeks	Open water feeder creeks through the marshes and across tidal flats.
Eelgrass and other submerged aquatic plant beds	Subtidal areas that are primary habitat for bay scallops and associated species.
Intertidal mud and sand flats	Open sand or mud flats that are submerged at high tide and exposed at low tide.
Salt marshes	Low and high fringing areas that are persistently wet.
Dredge material areas	Dredged materials become vegetated by pennywort and grasses and if left undisturbed undergo successional invasion by shrubs.
Shrub thicket/Maritime forest	Shrub forest areas on the upland island areas.
Dunes	Upland areas stabilized by grasses.
Sandy beaches	Intertidal areas of sandy beach and boat landing areas.

However, this assessment provided only minimal information regarding habitat types and function. To more accurately and methodologically account for the various habitat types within the Reserve components, in 2005 NCNERR participated as a pilot Reserve for the NERRS habitat and land use classification system. This effort categorized the habitats within the Reserves using a much improved classification system (Appendix 4).

The updated habitat map for Rachel Carson is presented at the subclass level in Figure 3.7. Areal statistics for habitat occurrence were calculated from the digital classification data and are provided as acreage and the percentage of total acres mapped for each habitat subclass (Table 3.5). Subtidal areas were not included in this assessment. Visual observations were made during field surveys to document predominant plant species for each habitat subclass. These data provide a framework for conducting more in-depth inventories of vegetation composition and conditions. Habitat subclasses at Rachel Carson are described in the following paragraphs, with representative photographs presented in Appendix 4.

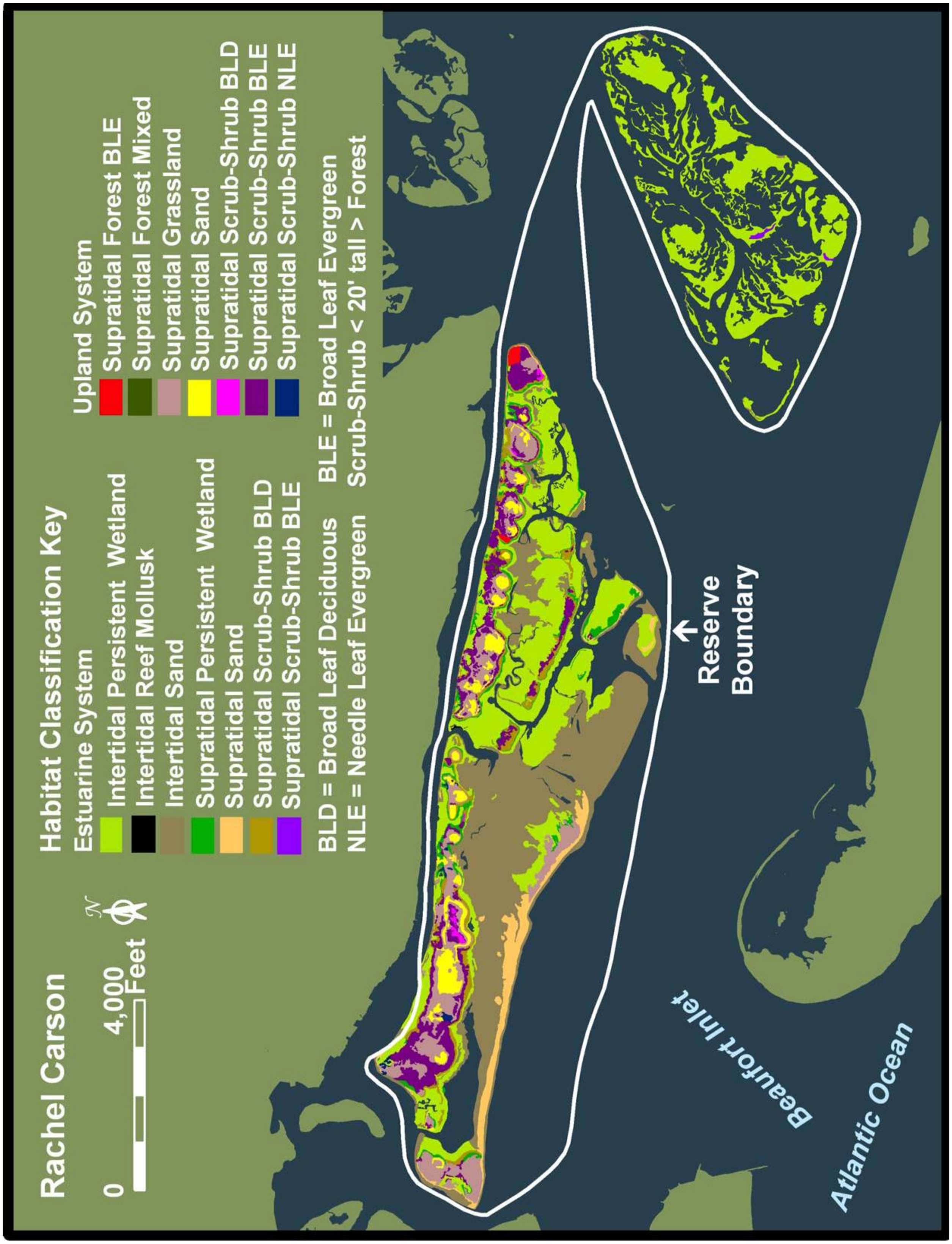


Figure 3.7: Rachel Carson 2004 habitat classification presented at the subclass level.

Table 3.5: Rachel Carson 2004 habitat classification areal statistics

Habitat Subclass	Area (Acres)	% of Total
Estuarine Intertidal Persistant Wetland	433.97	40.44
Estuarine Intertidal Sand	323.56	30.15
Upland Supratidal Grassland	90.48	8.43
Upland Supratidal Scrub-Shrub Broad Leaf Evergreen	75.59	7.04
Estuarine Supratidal Sand	38.88	3.62
Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous	37.92	3.53
Upland Supratidal Sand	33.61	3.13
Estuarine Supratidal Persistant Wetland	29.10	2.71
Upland Supratidal Scrub-Shrub Needle Leaf Evergreen	2.94	0.27
Upland Supratidal Forest Broad Leaf Evergreen	2.58	0.24
Upland Supratidal Scrub-Shrub Broad Leaf Deciduous	2.34	0.22
Estuarine Supratidal Scrub-Shrub Broad Leaf Evergreen	1.42	0.13
Upland Supratidal Forest Mixed	0.45	0.04
Estuarine Intertidal Reef Mollusc	0.16	0.01
Total Mapped Habitat Area	**1,073.00***	**100.00**
* Subtidal areas not included		

- The most dominant habitat type within the Rachel Carson component was Estuarine Intertidal Persistant Wetland, comprising over 40% of total habitat. This subclass is commonly known as the salt marsh. Areas of this subclass were found along the exterior edges of Carrot Island as well as nearly 100% coverage of the Middle Marsh area. At Rachel Carson this habitat type was dominated by Smooth Cordgrass (*Spartina alterniflora)*.

- Next in area coverage was the Estuarine Intertidal Sand subclass, making up 30% of total habitat. The majority of this subclass area was represented in the large tidal flats, but intertidal sand was also found around the perimeter of Carrot Island.

- The third most dominant class was Upland Supratidal Grassland, with 90 acres representing 8% of the total habitat. These areas were found in the interior portions of Carrot Island, interspersed with various scrub-shrub habitats and bare sand. This habitat subclass contained barrier island grass species such as Salt Meadow Hay (*Spartina patens)*, Sea Oats (*Uniola paniculata*), as well as cultivated lawn species such as Centipede (*Eremochloa ophiuroidesand*). These landscape grasses may have come from the manicured lawns across Taylor's Creek (Figure 3.1).

- Upland Supratidal Scrub-Shrub Broad Leaf Evergreen was located mostly in the interior portions of Carrot Island, bordering grasslands and marshes. The species found within this subclass are a mix of Yaupon (*Ilex vomitoria*), Wax Myrtle (*Morella cerifera* or *Myrica cerifera*), Laurel Oak (*Quercus laurifolia*), and Live Oak

(*Quercus virginiana)*. The Eastern Red Cedar (*Juniperus virginiana*), a needle leaf evergreen, is also found among the broad leaf evergreens, though is not dominant.

- The following subclasses comprised between 2-4 % of total habitat area and covered between 25-40 acres each (listed in decreasing order): Estuarine Supratidal Sand, Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous containing mostly Sea Ox-eye (*Borrichia frutescens*), and Glasswort (*Salicornia spp.*); Upland Supratidal Sand with ≤ 30% vegetative cover and Estuarine Supratidal Persistant Wetland, inhabited by a variety of grass species.

- The following habitats each covered less than 3 acres and 1% of total habit (listed in decreasing order): Upland Supratidal Scrub-Shrub Needle Leaf Evergreen dominated by Eastern Red Cedar (*Juniperus virginiana*); Upland Forested Broad Leaf Evergreen dominated by Live Oak (*Quercus virginiana)* and Upland Supratidal Scrub-Shrub Broad Leaf Deciduous, containing a mix of Marsh Elder (*Iva frutescens*), and Grounsel Tree (*Baccharis halimifolia*).

- Two habitats each included less than 0.05 acres and 1% of total: Upland Forested Mixed (containing a mix of pines and oaks) and Estuarine Intertidal Reef Mollusc consisting of live oysters and oyster shells.

3.7: Plants

The plant communities present within the Rachel Carson area are consistent with those of other barrier islands and marsh islands found in this part of the country. The dominant terrestrial plant species for each habitat subclass are listed in the preceding section. For a full species list refer to Appendix 5. The Natural Heritage Program has recognized several plant species found within the Rachel Carson community as threatened or significantly rare (Table 3.6). The Reserve is an important haven for these rare plants because it provides an area protected from development.

Large beds of marine seagrass are also found at the Rachel Carson Reserve. The seagrasses that have been documented within Rachel Carson include Eelgrass (*Zostera marina*), Shoalgrass (*Halodule wrightii*), and Wigeon Grass (*Ruppia maritime*) (Denault 2007). These SAV species provide habitat, food and refuge; produce oxygen; absorb nutrients; and reduce erosion by wave activity. Seagrass beds are currently being mapped by both NOAA staff and NCNERR staff. These efforts are highlighted under the current research activities in section 3.11.

Table 3.6: Species of special concern in and near Rachel Carson

State Status Codes: E = Endangered, T = Threatened, SC = Special Concern, SR = Significantly Rare, L = range limited to North Carolina and adjacent states.

Federal Status Codes: E = Endangered, T = Threatened, FSC = Federal Special Concern.

Major Group	Scientific Name	Common Name	State Status	Federal Status
Vascular Plant	*Amaranthus pumilus*	Seabeach Amaranth	T	T
Vascular Plant	*Dichanthelium caerulescens*	Blue Witch Grass	E	None
Vascular Plant	*Ipomoea imperati*	Beach Morning-glory	SR	None
Vascular Plant	*Lysimachia asperulifolia*	Rough-leaf Loosestrife	E	E
Vascular Plant	*Polygonum glaucum*	Seabeach Knotweed	SR	None
Vascular Plant	*Solidago verna*	Spring-flowering Goldenrod	T	FSC
Vascular Plant	*Trichostema sp. 1*	Dune Bluecurls	SR	FSC
Invertebrate Animal	*Busycon canaliculatum*	Channeled Whelk	SC	None
Invertebrate Animal	*Busycon carica*	Knobbed Whelk	SC	None
Invertebrate Animal	*Busycon contrarium*	Lightning Whelk	SC	None
Invertebrate Animal	*Chaetopterus variopedatus*	Parchment Tubeworm	SC	None
Bird	*Aimophila aestivalis*	Bachman's Sparrow	SC	FSC
Bird	*Ammodramus henslowii susurrans*	Eastern Henslow's Sparrow	SR	FSC
Bird	*Anhinga anhinga*	Anhinga	SR	None
Bird	*Botaurus lentiginosus*	American Bittern	SR	None
Bird	*Charadrius melodus*	Piping Plover	T	T
Bird	*Charadrius wilsonia*	Wilson's Plover	SR	None
Bird	*Coturnicops noveboracensis*	Yellow Rail	SR	None
Bird	*Dendroica virens waynei*	Black-throated Green Warbler - Coastal Plain Population	SR	FSC
Bird	*Egretta caerulea*	Little Blue Heron	SC	None
Bird	*Egretta thula*	Snowy Egret	SC	None
Bird	*Egretta tricolor*	Tricolored Heron	SC	None
Bird	*Gelochelidon nilotica*	Gull-billed Tern	T	None
Bird	*Passerina ciris ciris*	Eastern Painted Bunting	SR	FSC
Bird	*Pelecanus occidentalis*	Brown Pelican	SR	None
Bird	*Plegadis falcinellus*	Glossy Ibis	SC	None
Bird	*Rynchops niger*	Black Skimmer	SC	None
Bird	*Sterna hirundo*	Common Tern	SC	None
Bird	*Sternula antillarum*	Least Tern	SC	None
Amphibian	*Bufo quercicus*	Oak Toad	SR	None
Reptile	*Caretta caretta*	Loggerhead Turtle	T	T
Reptile	*Chelonia mydas*	Green Sea Turtle	T	T
Reptile	*Heterodon simus*	Southern Hognose Snake	SC	FSC
Reptile	*Lampropeltis getula sticticeps*	Outer Banks Kingsnake	SC	None
Reptile	*Lepidochelys kempii*	Atlantic Kemps Ridley	E	E
Reptile	*Malaclemys terrapin centrata*	Carolina Diamondback Terrapin	SC	None
Reptile	*Nerodia sipedon williamengelsi*	Carolina Water Snake	SC	None
Reptile	*Seminatrix pygaea*	Black Swamp Snake	SR	None
Reptile	*Sistrurus miliarius*	Pigmy Rattlesnake	SC	None
Mammal	*Neotoma floridana floridana*	Eastern Woodrat - Coastal Plain Population	T	None
Mammal	*Trichechus manatus*	West Indian Manatee	E	E

Data from the North Carolina Natural Heritage Program

3.8: Animals

Animal presence within the Reserve is high compared to other coastal areas of comparable size due to the diverstiy of habitats within the Rachel Carson Reserve. Within the Reserve, there is a variety of upland and supratidal habitats which offer foraging habitats for birds, mammals, and crustaceans. The estuarine waters and subtidal habitats surrounding Carrot Island and Middle Marsh are important nursery grounds for many fish species. The Rachel Carson Reserve also provides valuable habitat for mollusks, invertebrates and insects (See Appendix 5 for a full species list).

A: Invertebrates and Zooplankton

Crustaceans inhabit the intertidal and supratidal areas within Rachel Carson. Common crustaceans for this area include: Ghost Crab (*Ocypode sp.*), Fiddler Crab (*Uca sp.*), Mole Crab (*Emerita talpoida*), Beach Flea (*Orchestia sp.*), Sand Shrimp (*Crangon septemspinosa*), Horseshoe Crab (*Limulus polyphemus*), Blue Crab (*Callinectes sapidus*), and other crab and shrimp species (Taggart and Henderson, 1998). Research by an NCNERR Graduate Research Fellow examined the way female Blue Crabs use tidal currents to move. Results indicated that by timing vertically movements with tidal cycles, female crabs could control the direction they moved relative to the Ocean. This research also showed that the Rachel Carson Reserve was an important stopover for migrating female Blue Crabs (Carr et. al. 2004)

The soft substrates within the Rachel Carson Reserve provide habitat for forty-seven species of invertebrates (Taggart and Henderson, 1998), including the Eastern Oyster (*Crassostrea virginica*), several species of clams, Atlantic Bay Scallop (*Argopecten irradians*), Ribbed Mussel (*Modiolus demissus (Dillwyn)*), many gastropods and a wide variety of benthic species. Four invertebrates found within the boundaries of the Rachel Carson Reserve, the Channeled Whelk (*Busycon canaliculatum*), the Knobbed Whelk (*Busycon carica*), the Lightening Whelk (*Busycon contrarium*), and the Parchment Tubeworm (*Chaetopterus variopedatus*), have been given special concern status by the North Carolina Natural Heritage Program (Table 3.6) (Taggart and Henderson, 1998).

Several studies regarding oysters and scallops have been conducted in the Reserve. Scallop numbers have been declining in recent years. Studies have found that the area is starved for larvae recruitment (Peterson and Summerson 1992). The reasons behind this larvae recruitment issue are still being investigated. It is also believed that the scallop population is suffering from heavy predation by sting rays. A NCNERR GRF fellow conducted research into oysters in Middle Marsh. He examined how habitat setting influenced restored oyster communities. He observed that restored oyster reefs enhanced the abundance of resident invertebrates (Grabowski et al. 2005).

B: Fishes

The waters around Rachel Carson serve as nursery and habitat areas for many commercially important fisheries. Over 50 species of fish have been documented as present around Rachel Carson (Taggart and Henderson, 1998). NOAA's Fisheries Service has conducted a sampling program since 1985 to document the fish larvae present in the waters passing under the bridge between Piver's island and the mainland (Figure 3.1). This program called “bridgenet” provides a long term quantification of the nekton using the Rachel Carson area as a nursery. Table 3.7 shows the most abundant species that have been documented by this sampling program from 1985-2002. Sampling has continued since 2002, although larvae identification has not been completed. Preserved samples will be analyzed as resources allow. Information regarding this sampling program can be obtained from Dr. Gretchen Beth Martin at the NOAA Beaufort Laboratory.

Table 3.7: Species collected by NOAA Fisheries Service Bridgenet sampling program 1985-2002.

Scientific Name	Common Name	Number collected
Leiostomus xanthurus	Spot	215054
Lagodon rhomboids	Pinfish	154973
Micropogonias undulates	Atlantic Croaker	74242
Brevoortia tyrannus	Atlantic Menhaden	48973
Myrophis puctatus	Speckled Wormeel	26967
Myrophis puctatus (leptocephalus)	Speckled Wormeel Lepto	23451
Engraulidae	Anchovy	18652
Paralichthys albigutta	Gulf Flounder	9852
Orthopristis chrysoptera	Pigfish	8613
Gobiidae	Goby	6260
Paralichthys lethostigma	Southern Flounder	6254
Mugil cephalus	Striped Mullet	4824
Paralichthys dentatus	Summer Flounder	2173

NCNERR GRF work has also examined the habitat selection, foraging effort, and schooling behavior of Red Drum, (*Sciaenops ocellatus*) within Rachel Carson. Red Drum showed strongest preference for sand and second strongest preference for oyster reef. Sandy habitats were selected most often for both active foraging and sedentary activity. While reefs were often the second choice of red drum, they were used most for sedentary activity. Red Drum used grassbeds infrequently and almost exclusively for foraging. Red Drum occurred mostly in schools or groups in all three habitats and were seen isolated from each other rarely (Powers 2005).

In addition to Red Drum, the Reserve is home to many other commercially important finfish. Middle Marsh is heavily utilized for foraging by Speckled Trout (*Cynoscion nebulosus*) and Flounder (*Paralichthys dentalus* and *Paralichthys lethostigma*). Juvenile members of the Snapper-Grouper complex are often observed feeding in Middle Marsh along seagrass beds and oyster reefs. Spot (*Leiostomus xanthurus*), Croaker (*Micropogonias undulates*), Menhaden (*Brevoortia tyrannus*) and Striped Mullet (*Mugil cephalus*) are also frequently observed in the Reserve, especially in later summer early fall. The deep channels running through the Reserve attract Bluefish (*Pomatomus saltatrix*) and Spanish Mackerel (*Scomberomorus maculates*). Many species of sharks and rays are also found within the Reserve boundaries.

C: Reptiles and Amphibians

Most reptile and amphibian sightings occur in the upland habitats and include several species of lizards, snakes, frogs and toads. The Eastern Box Turtle (*Terrapene carolina*) is the most frequently observed terrestrial turtle on the Reserve. The Loggerhead Sea Turtle (*Caretta caretta*), a federally threatened species (Table 3.6), may be found on or around the Rachel Carson Reserve. Also present within the area are the Green Sea Turtle (*Chelonia mydas*), Atlantic Kemps Ridley (*Lepidochelys kempii*) and the Carolina Diamondback Terrapin (*Malaclemys terrapin centrata*). On rare occasions the ocean side boundary of the Rachel Carson Reserve is used by these marine turtles for nesting.

D: Birds

Over 200 species of birds have been documented on the Rachel Carson Reserve. This site is within the primary fall migration route for many species of birds (Atkinson, et al. 1998). The Rachel Carson component is commonly utilized by the following bird species: Snowy Egret (*Egretta thula*), Little Blue Heron (*Egretta caerulea*), Tricolored Heron (*Egretta tricolor*), Glossy Ibis (*Plegadis falcinellus*), Gull-billed Tern (*Sterna nilotica*), and Black Skimmer (*Rynchops niger*) (Atkinson, et al. 1998). Seasonal nesting occurs within the Reserve by: gulls, terns, and skimmers on the dunes of Bird Shoal, while herons and egrets have a rookery within the Middle Marshes shrub thicket (Atkinson, et al. 1998). Federally threatened Piping Plovers (*Charadrius melodus*) and state listed significantly rare Wilson's Plovers (*Charadrius wilsonia*) have been observed feeding within the Reserve component (Table 3.6). Two species of Raptor have been observed by staff on the Rachel Carson Reserve, the Osprey (*Pandion haliaetus*) and Red-tailed Hawk (*Buteo jamaicensis*).

E: Mammals

Mammals found within the Reserve include Raccoon (*Procyon lotor*), Gray Foxes (*Urocyon cinereogentus*), Marsh Rabbits (*Sylvilagus palustris*), and feral horses (Atkinson, et al. 1998). As of January 2007, the feral horse population was up to 42 individuals (see section 3.9). Marine mammals are also found in the waters surrounding the Reserve. The Atlantic Bottlenose Dolphin (*Tursiops truncatus*) is the most common marine mammal sighted. Occasionally a stray West Indian Manatee (*Trichechus manatus*) will visit the Reserve, although sightings are rare.

3.9: Invasive Species

There are several documented invasive species present on the Rachel Carson Reserve. These include the Tamarisk Tree (*Tamarix ramosissima*), Russian Olive (*Elaeagnus angustifolia*), Nutria (*Myocaster coypus*) and feral horses. The Tamarisk Tree or Saltcedar is a native species found in Eurasia and Africa. It was imported as an ornamental shade tree and for its erosion control and wood production potential (Figure 3.8) (Graetz 1973). A mature tree can produce up to 600,000 seeds each year and can

Figure 3.8: Tamarisk Tree at Rachel Carson.

consume up to 300 gallons (1,135 L) of water per day. This tree spreads rapidly by seed and root propagation. The trees can grow up to one foot (0.3 m) per month and range from 5-20 ft (1.5-6 m) tall when mature. Monitoring of this tree began on the Rachel Carson Reserve in June of 2001 and has continued every summer since then with using hand-held GPS units to plot the location of the trees. Figure 3.9 shows the locations of the Tamarisk trees on Rachel Carson from the mapping effort that was completed during the summer of 2006. Tamarisk out-competes native vegetation by consuming vast amounts of water and by exuding salt from its leaves. These processes increase the Chloride concentration of the soil beyond the tolerance of most native species (Stein and Flack 1996). Another problem specific to the Rachel Carson Reserve is that the trees' water usage could dry up the watering holes that the feral horses use. Efforts to monitor the spread of the trees will continue as will efforts to remove them using cut stump herbicide application. A pilot removal effort using this method was conducted in 1999. This effort showed promise as an effective management strategy. The primary lesson learned from this pilot study was that repeat herbicide applications are required to quell sprouts that emerge from the original tree's cut stump. One herbicide application was not enough to achieve effective control.

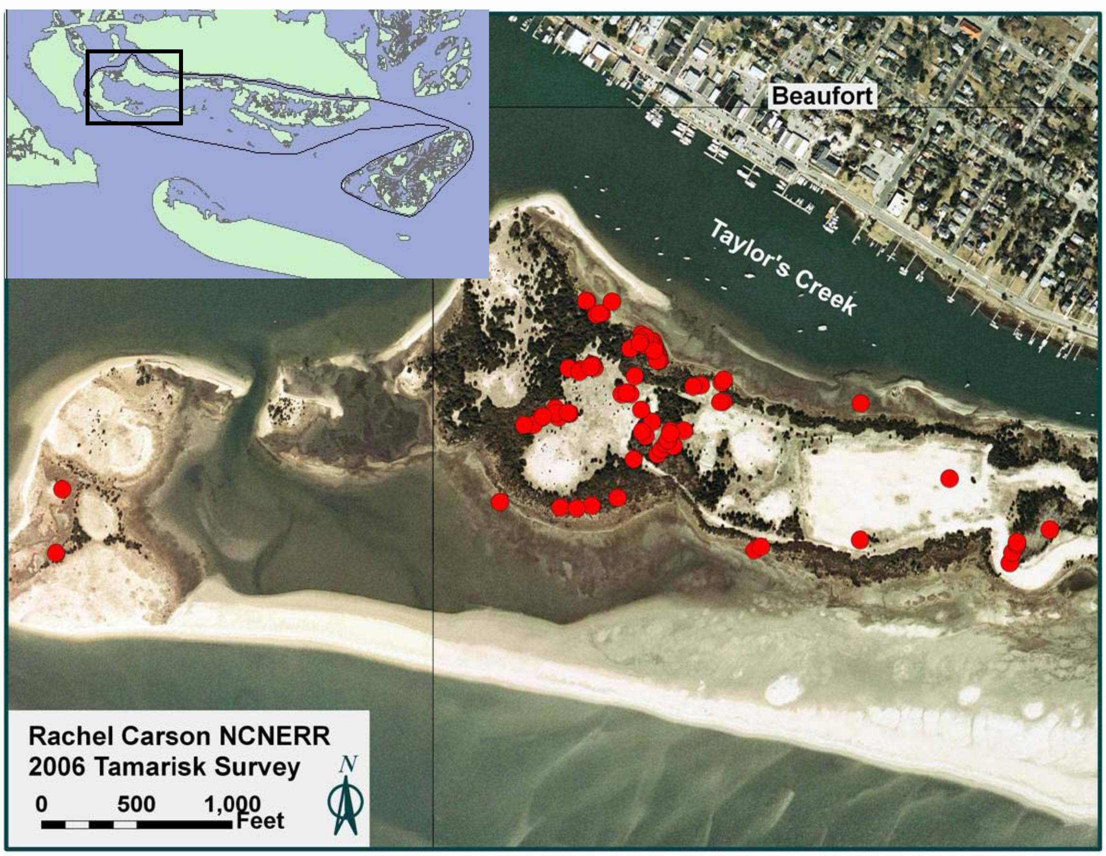


Figure 3.9: Tamarisk locations (red dots) at Rachel Carson from the 2006 mapping effort. Map shows location of aerial photo on reserve.

Figure 3.10: Horse and foal at Rachel Carson

The upland areas that are now part of the Rachel Carson Reserve were used as grazing areas for livestock, by local residents starting in the 1940s. As a result of this practice, a feral population of horses is now present on the Reserve (Figure 3.10). These horses are not part of the natural biota for the island and their presence has caused problems and interference with the native communities of the Reserve. The main food supply of the feral horse is Smooth Cordgrass (*Spartina alternaflora*). Studies have shown feral horse populations may adversely affect biomass, percent cover, height, density and surface cover of *Spartina* and more importantly decrease seed production (Hay and Wells, 1988). Thus, horse activity decreases the marshes' ability to provide wave dampening; fish habitat and erosion protection; and may eventually lead to marsh loss. The action of the horses' hooves can also hasten erosion of island sediments, and can cause damage to colonial bird and sea turtle nests.

Despite the harsh conditions the horses thrived on the Reserve and during the late 1980s and early 1990s causing the population to exceed the Reserve's carrying capacity. This led to massive malnutrition and several deaths. The horses are considered a cultural resource so management action was required to alleviate the over crowding. A birth control program was initiated to stem new births. This coupled with natural morality has helped the horse population get near the target number of 40 horses. This method was chosen because it has been proven effective in wild horse populations located on Cape Lookout National Seashore (Figure 3.1) and Assateague Island National Seashore on the Maryland – Virginia border. Since the darting process started, there have been 8 births at Rachel Carson.

To properly implement the birth control program, an accurate record of the horse population must be maintained. Individual horses are identified, photographed, and maintained in a notebook. Each horse is tracked in the notebook for births, general health, social habits and eventually death. Beyond the birth control program, the horse population is treated as a wild herd. The Reserve's staff from the Beaufort office oversees the horse management for Rachel Carson.

Figure 3.11: Picture of a Nutria (Myocastor coypus).

Table 3.8 lists other invasive species that are currently known to exist on the Rachel Carson Reserve. To date, no investigations have been done on these species other than to confirm that they are present. Future work will need to examine the impact of these species. The nutria or *Myocastor coypus* in particular are potentially very problematic because their feeding habits cause damage to vegetation and destruction of wetland habitats (Figure 3.11).

Table 3.8: Other invasive species found on Rachel Carson

Scientific Name	Common Name
Ambrosia artemisiifolia	Ragweed
Commelina communis	Dayflower
Conyza Canadensis	Horseweed
Eupatorium capillofolium	Dog fennel
Melilotus alba	White sweet clover
Salsola kali	Russian thistle
Xanthium stumarium	Cocklebur
Cortaderia selloana	Pampas grass
Codium fragil	Dead man's fingers
Myocastor coypus	Nutria
Eremochloa ophiuroidesand	Centipede grass
Data from NCNERR staff observations.	

3.10: Stressors

The Rachel Carson Reserve component is exposed to a variety of stressors, both natural and anthropogenic (man-made). Natural stressors include hurricanes and Nor'Easters, sea level rise, and drought. Anthropogenic stressors include altered land use, pollution, nutrient loading, and habitat disruption. Some of the key stressors are discussed in detail below.

A: Pollution/eutrophication

The primary concern in this category for the Rachel Carson Reserve is fecal contamination of shellfish beds. Fecal contamination enters surface waters from a variety of sources: failing septic tanks, spills and leaks from municipal sewer systems, illegal pump outs from vessels and defecation by resident fauna. There has been a large body of work regarding fecal contamination within the Rachel Carson Reserve. Three NCNERR GRF fellows have examined the waters around Rachel Carson for fecal contamination. They have found that the waters are susceptible to episodic loading associated with runoff events (Gregory et al. 2006; Coulliette 2007; Love 2007). This coupled with the increased development that has occurred in the region (see below) suggest that more acres of shellfish beds may be closed in the future.

B: Sea Level Rise and Erosion

Sea level rise and erosion is a serious concern in coastal areas worldwide (Pilkey and Cooper 2004). North Carolina is especially susceptible because a large portion of the Coastal Plain has very low relief. The Intergovernmental Panel on Climate Change predicts increased rates of global sea-level rise over the next century in direct response to known global climate warming (IPCC 2001). Increased rates of sea-level rise will adversely impact coastlines of North Carolina in the following ways:

- Accelerated rates of coastal erosion and land loss;
- Increased economic losses due to flooding and storm damage;
- Increased loss of urban infrastructure;
- Collapse of some barrier island segments; and
- Increased loss of estuarine wetlands and other coastal habitats (Riggs 2003).

Most of the estuarine shorelines in North Carolina are eroding in response to the ongoing long-term rise in sea level. The weighted average for the recession of all shoreline types within the highly variable regional setting is -2.7 ft yr^{-1} (0.8 m yr^{-1}) (Riggs 2003). Many areas within the Rachel Carson Reserve are less than 1ft (0.3 m) above present sea level. Consequently, large areas of the Reserve will be converted to subtidal habitat if accretion rates can not keep up with sea level rise (see Section 3.11 C).

Erosion, largely driven by storm processes, results in the systematic loss of both uplands and wetlands through time (Riggs 2003). Erosion can also be accelerated by man-made activities such as boating (Rogers and Skrabal 2003). Recreational and commercial boats can generate closely spaced, steep waves that are particularly prone to cause erosion. The Rachel Carson Reserve has experienced this type of erosion on the east end of Carrot Island where Taylor's Creek enters Back Sound. At this location, the no wake zone of Taylor's Creek ends and mariners power up just as they are rounding the end of Carrot Island. During power up the largest wakes tend to be produced because the boat is displacing the most water. Aerial photography was used to calculate the erosive loss on the east end of Carrot Island from 1994-2004 (Figure 3.12). This work, conducted by Jacquie Ott (NCNERR GIS specialist), clearly shows the loss of Reserve property due to erosion. Of the nine transects investigated, between 12 and 45 ft (3.6 and 13.7 m) have been lost. This erosion has undercut the high bluff that is present on this end of the Reserve resulting in the loss of several upland forest trees. This study clearly shows the impact boat wakes can have. A rise in sea level will only exacerbate this problem. Management options to alleviate this issue are currently being considered. Some of the options include extending the no wake zone, installing a natural breakwater (oyster reef) and conducting programs to educate local boaters.

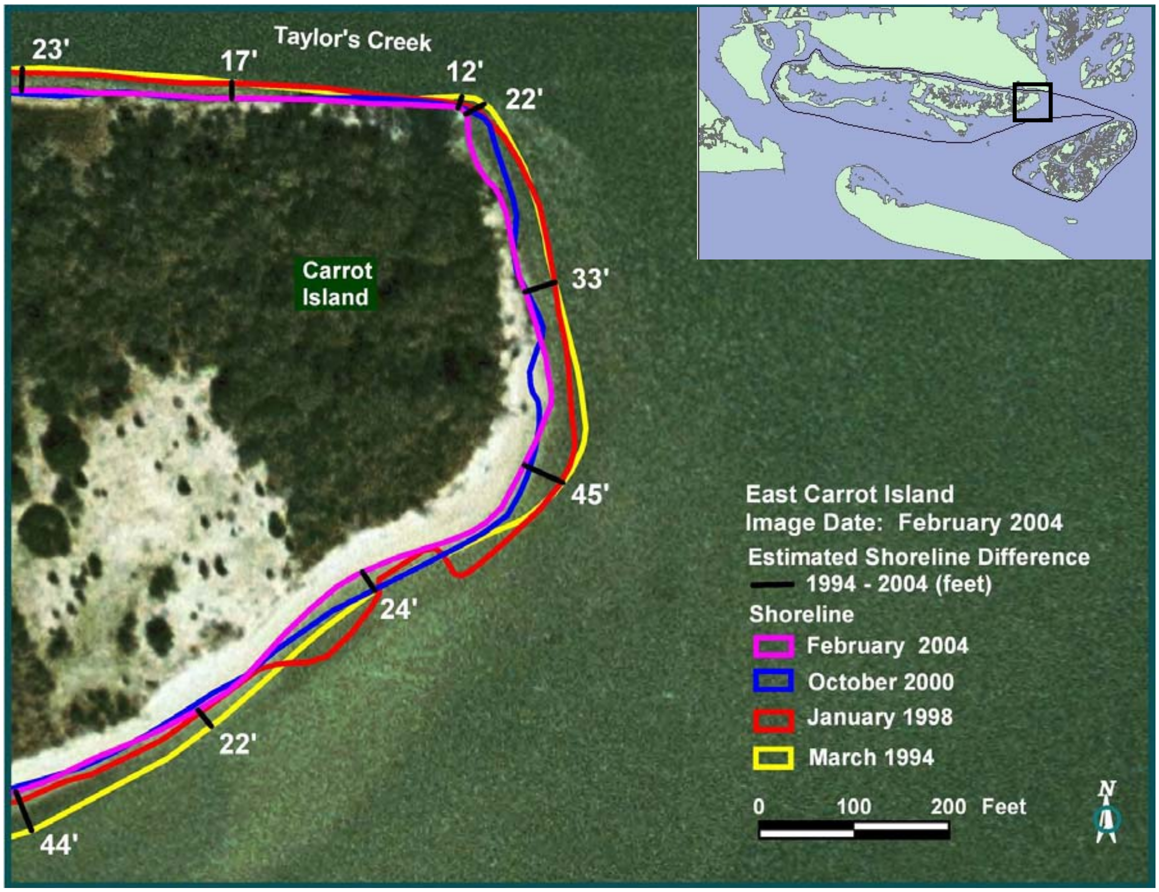


Figure 3.12: Historical shorelines on the east end of Rachel Carson (Carrot Island) since 1994, showing significant erosion.

C: Altered Land Use

The type of land cover present is a critical issue because how the land is used and the type of cover on it has large impacts on its ability to sequester nutrients and pollution rather than convey them to surface waters. Natural land covers with vegetative cover such as forest and marsh have large buffering capacities. They tend to trap nutrients and sediment prior to them entering surface waters. Developed land tends to have very little capacity to absorb nutrients and pollution. This is because developed land has increased impervious surfaces such as roofs, roads, and parking lots. These surfaces do not let water infiltrate the ground and high percentages of impervious surfaces have been correlated with degraded water and sediment quality (Holland et al. 2004, Mallin et al. 2000b). Consequently stormwater runs off these surfaces, picking up whatever contaminants and nutrients are on them and rapidly moves these materials to surface waters (Mallin et al. 2000b, Mallin et al. 2001).

Carteret County's population had an estimated increase in percent population growth of 11.7 % from 1990-2000, and a projected increase of 13.9% for 2000-2020 (N.C. Department of Environment and Natural Resources 2007). Most of this population increase has occurred in the western part of the county where the Rachel Carson Reserve is located. In addition to residential development, scattered commercial and industrial development continues to occur throughout the county. To accurately account for this development, the land use of the county was mapped using land cover data from NOAA's Coastal Change Analysis Program using the protocol presented in Appendix 4. The two most recent years that data is available for are 1991 and 1997. Figure 3.13 shows the land cover maps for 1991 (panel a) and 1997 (panel b) for the Rachel Carson watershed (United States Geological Survey - Hydrologic Cataloging Unit 03020106). See Appendix 4 for detailed methodology. This delineation covers all the areas of the White Oak River Basin as shown in Figure 3.2 except for the New River sub-basin. The major land cover types were water (38%), Evergreen Forest (19% in 1991, 16% in 1997) and Palustrine Forested Wetland (11% both years) associated with the Croatan National Forest in the Western region of the watershed. Low and High Density Developed (2%) was concentrated in the barrier island communities of Bogue Banks as well as Beaufort and Morehead City.

For clarity the changes that occurred between 1991 and 1997 have been grouped into three categories: 1) decreased vegetation cover (of any type), 2) increased vegetation cover (of any type), and 3) a change from one type of non-vegetated cover to another (neither an increase of decrease of vegetation). The decrease in vegetation cover category includes all areas where the Land Cover changed between 1991 and 1997 to a class that characterizes conditions with generally less plant cover or biomass. Examples of this category are a transition from Forested to Grassland or Scrub-shrub to Low Density Development. The increase in vegetation cover category was assigned to all areas where the Land Cover changed to a class that represents generally greater plant cover or biomass. Examples of this category are succession of grassland to Scrub-Shrub and Scrub-Shrub to Forested. The change in non-vegetated cover category designates all areas that had different non-vegetated land cover classes in 1991 and 1997. Examples included water to unconsolidated shore, unconsolidated shore to bare land and bare land to low-density developed. Figure 3.14 and Table 3.9 show the changes between 1991 and 1997 associated with these three groups.

Table 3.9: Change in land cover from 1991 to 1997 in the Rachel Carson watershed

Category	Acres	% of total
Total mapped area	752,337	n/a
Water area	285,941	38.0
Total land area	466,396	62.0
Decrease in vegetative cover	36,033	7.7
Increase in vegetative cover	21,953	4.7
Change from one unvegetative cover to another	1,041	0.22
Unchanged land cover	407,369	87.3
Net loss of vegetation = 3.0%		
Percent of land area with changed cover types = 13%		

Changes that occurred between 1991 and 1997 affected 13% of the watershed. The increase in vegetated conditions (5%) was due primarily to succession of Grassland to Scrub/Shrub and Palustrine Scrub/Shrub Wetland to Palustrine Forested Wetland along the western and northern edges of the watershed. These areas are primarily located in protected natural areas. The 8% decrease in vegetative cover consisted primarily of conversion of Evergreen Forest to Scrub/Shrub and Grassland.

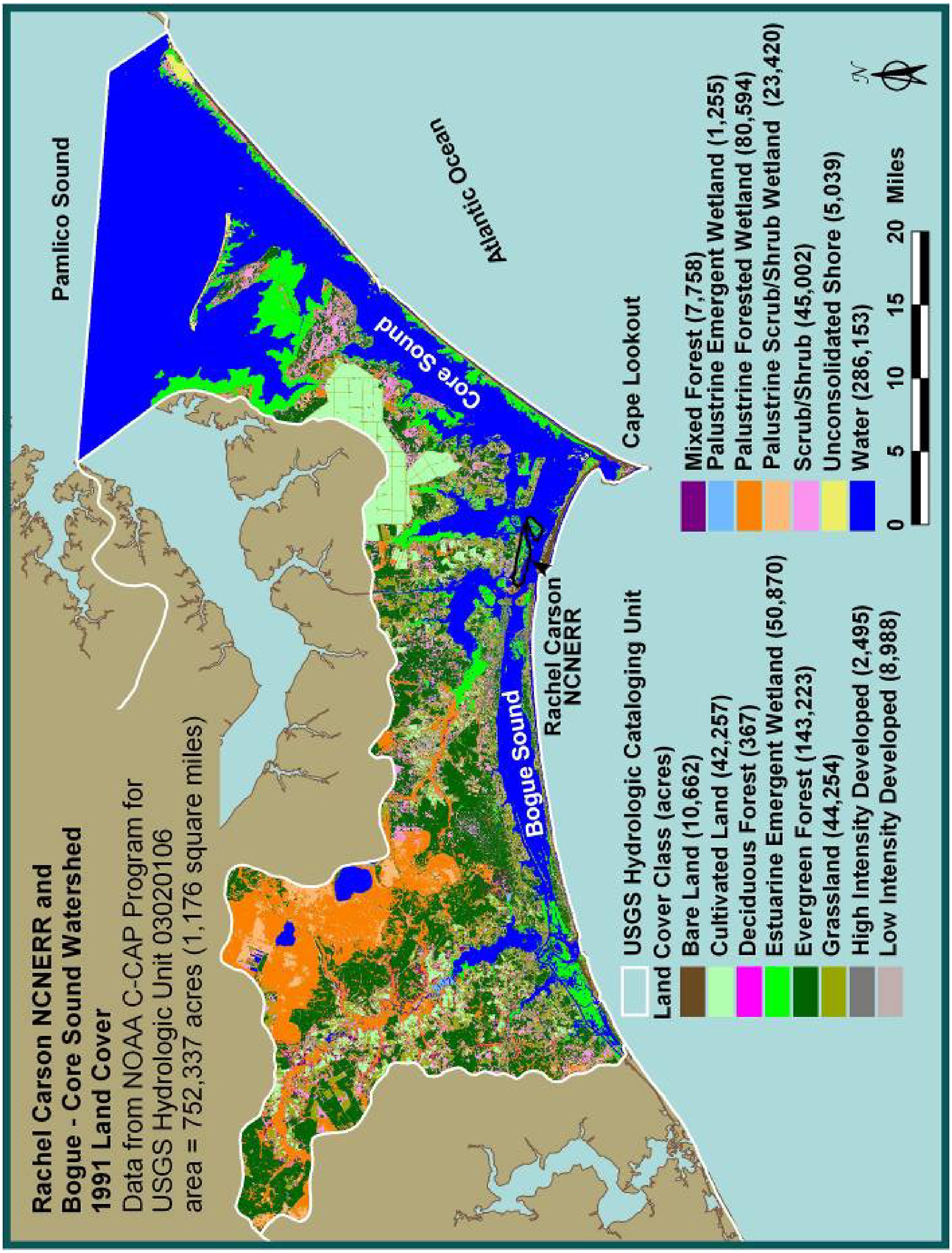


Figure 3.13a: Land use classification from 1991 in the Rachel Carson watershed.

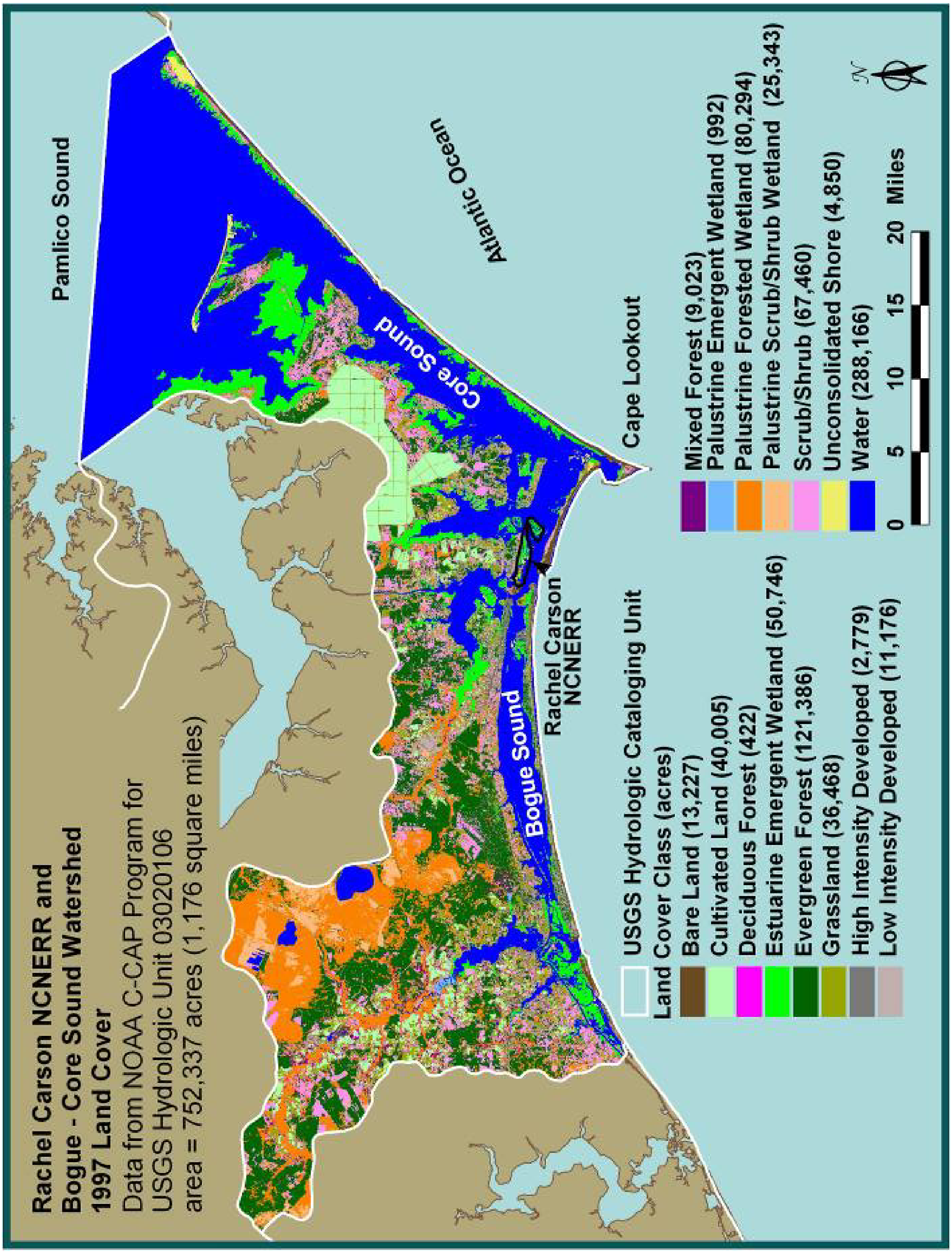


Figure 3.13b: Land use classification from 1997 in the Rachel Carson watershed.

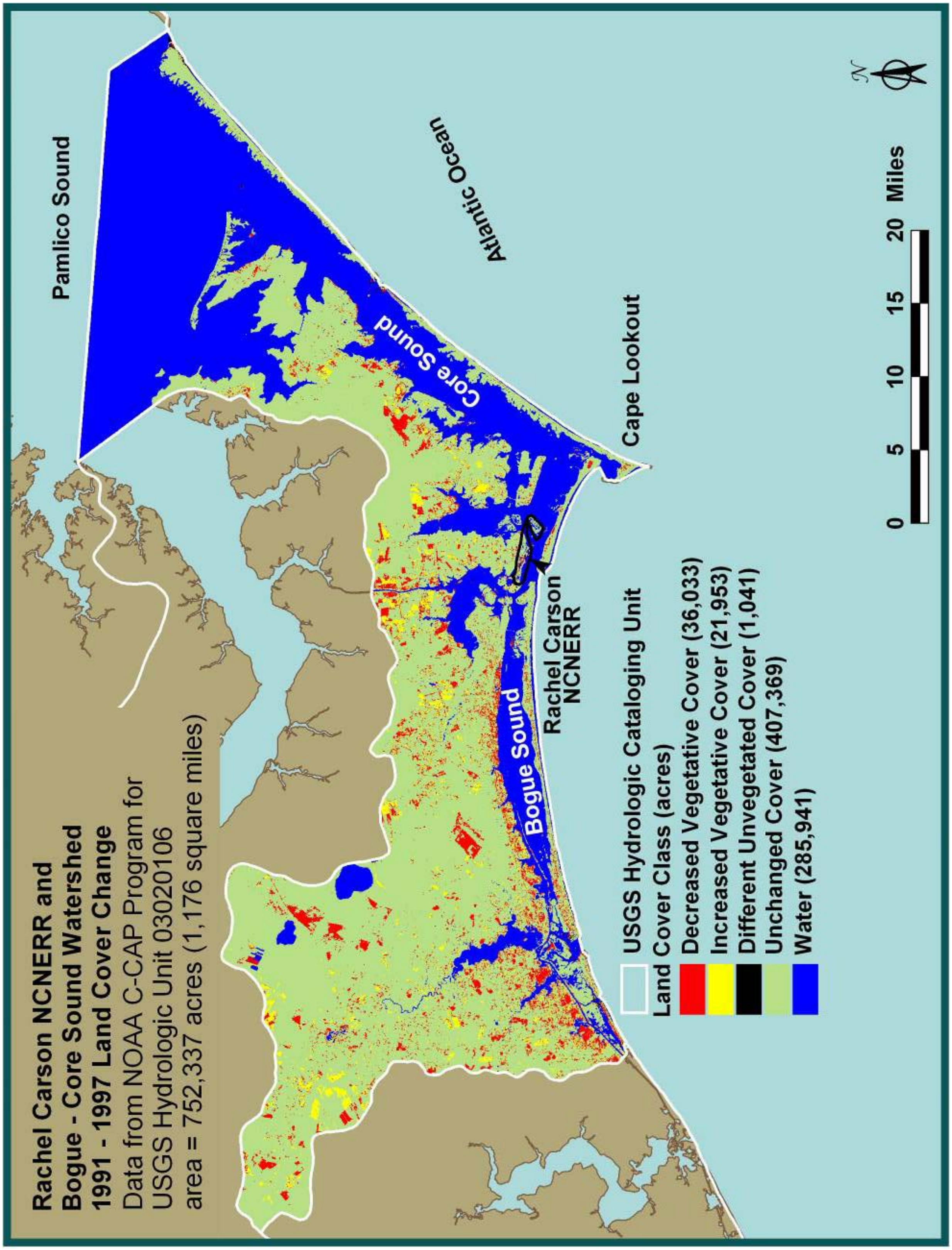


Figure 3.14: Changed land cover from 1991 to 1997 in the Rachel Carson watershed.

The net loss of vegetated land cover between 1991 and 1997 was 3%, principally surrounding Bogue Sound. While 3% seems like a low value, as noted above, this represents only the initial pulse of increased development within the area. Since 1997, development pressure has increased. In 2006 alone three major condominium projects occurred on the grounds of former low density developments. Decreased vegetative cover has been unequivocally linked to declines in water quality (Mallin et al. 2000b, Mallin et al. 2001). Less vegetation leads to increased runoff and less filtering capacity within the watershed. This is particular troubling for the Rachel Carson area given the susceptibility to eutrophication that the region has exhibited (see above section). It is expected that a much greater loss of vegetation cover will be detected in the time period since 1997.

D: Public Use

The Rachel Carson Reserve is open to the public for enjoyment. Fishing, boating, sailing, kayaking, shellfishing and shelling are all common recreational activities on and around the site. The island of Town Marsh has a marked self-guided trail that leads participants through the different estuarine habitats. Areas of the Reserve are heavily utilized as a destination by individuals with private boats. These activities lead to a substantial litter problem on the Reserve. Clean Sweeps are conducted at least twice annually by Reserve staff and volunteers. During these activities many (10+) bags of trash are removed from the Reserve. Unleashed dogs are also a constant problem on the Reserve. Dogs tend to chase colonial nesting birds disrupting feeding, breeding, and nesting.

3.11: Research Activities

The information in this section is in a rapid state of flux. Research projects are constantly being initiated, executed and completed. As a result, this section will rapidly become dated. Despite this complication, it is still beneficial to describe the current body of research in this manner. The past projects represent a large foundation which future projects can utilize as planning guides. The projects currently being worked on are designed to address current high priority coastal management issues. Thus, in addition to the actual research results, these projects will provide future interested parties with awareness into what the high priority issues were for the Reserve at this time. The needed research represents current knowledge gaps that need to be addressed. While future projects may address some of these, the underlying issues such as eutrophication and sea level rise will still be valid.

A: Research Facilities

The NCNERR office in Beaufort, N.C. is located at the NOAA Center for Coastal Fisheries and Habitat Research. NCNERR and the administrative branch of the NOAA lab share a building. This building provides office space for the research coordinator as well as for Reserve management and education staff. The co-location of staff provides great opportunity for cross sector collaboration. The building was not designed to provide support for research activities. There is a common room with counters and a sink that can be used for small clean research related activities. There are two boats available for research activities in the Beaufort office, and access to the site is ideal.

To make up for the lack of research facilities within the NCNERR-NOAA building, agreements have been made between NCNERR and several of the local marine laboratories in the region. The research coordinator has access to laboratory space at the University of North Carolina – Institute of Marine Science and at the NOAA Beaufort laboratory. Additional research facilities are potentially available through the Duke Marine Lab and North Carolina State's Center for Marine Science and Technology, although formal agreements have not been pursued at this point. The space available from these local marine research facilities provides the research coordinator with space and equipment to conduct most Reserve related research activities.

B: Historical Research Activities

There has been a large body of research conducted at the Rachel Carson Reserve since its dedication. These are documented in Appendix 6 the bibliography of work conducted within NCNERR. Carteret County has marine labs from NOAA, Duke University, North Carolina State University, The University of North Carolina at Chapel Hill, and also the headquarters for the N.C. Division of Marine Fisheries. All of these groups have conducted extensive research in and near the Rachel Carson Reserve. Historically, most of the NCNERR's GRF's have been based in Carteret County and used the Rachel Carson Reserve as their field site.

The research that has been conducted at the Reserve covers a broad range of topics. Projects mentioned previously in this chapter will not be relisted here. There have been numerous studies examining shellfish including the Eastern Oyster (*Crassostrea virginica*) and Scallop (*Argopecten irradians*). These projects have provided knowledge regarding the habitat value of oyster reefs, larvae recruitment, predator interaction, and restoration methods (Peterson and Summerson. 1992; Grabowski et al. 2005). There has also been a large body of work examining the spatial coverage of seagrass beds and their interaction with ecosystem components (Ferguson et al. 1993; Fonseca et al. 2001; Biber et al. 2005; Denault 2007). Several projects including one funded by NOAA's Cooperative Institute for Coastal and Estuarine Environmental Technology (Sobsy et al. 2006) have examined the amounts, source, and fate for fecal contamination found within the waters of the Reserve (Gregory et al. 2006; Coulliette 2007; Love 2007). Researchers from NOAA's Center for Coastal Environmental Health and Biomolecular Research in Charleston, SC recently completed a project at Rachel Carson examining the sediments in the Reserve using an EPA-Environmental Monitoring and Assessment Program style sampling design. The results of this project showed that the overall condition of the sediments within the Reserve was good and contaminant loads were relatively low (Cooksey and Hyland 2007). All of these and the many others listed in the bibliography help create a great base of knowledge for the Rachel Carson Reserve.

C: Current Research Activities

There are many research and monitoring activities currently being conducted at the Rachel Carson Reserve. Some of these projects are being conducted by Reserve staff while others are being done by outside researchers. NCNERR staff from all sectors is engaged in tracking the invasive Tamarisk tree on the Reserve. Information about this project is located in section 3.9. The Bridgenet sampling program discussed in section 3.8 is also still being conducted. The NCNERR-National Park Service water quality monitoring discussed in section 3.4 is also ongoing.

Two separate efforts are engaged in examining the geographic location, species makeup and density of SAV within the Reserve. NCNERR staff and interns are using on the ground methods to identify seagrass beds and map their size and species make up. The most recent efforts from this found previously unknown beds of grass on the front of Town Marsh and Carrot Island. The NOAA lab in Beaufort is using aerial photography and GIS methods to identify sea grass beds within the Reserve. Coordination between these two projects is underway and will continue into the future. The end result of these projects is to identify all areas within the Reserve that currently has seagrass beds. This will provide an ideal baseline to track future changes. This is an important issue because declines in SAV coverage can be used as an indicator of declining water quality.

A program to document the number and species of birds using the Reserve in winter as part of the Audubon Christmas Bird Count is also ongoing. The annual Christmas bird counts are conducted by a local volunteer and bird expert John Fussell. He has been doing the Christmas bird counts for several years. The information from these counts is available from the Audubon Society at (http://www.audubon.org/bird/cbc/history.html). He also conducts census data for nesting Piping Plovers, a species of special concern during the breeding season.

Dr. Dan Rittschoff a faculty member from the Duke University Marine Lab continues several research projects that partially utilize the Rachel Carson Reserve. Dr. Rittschoff's work includes: 1) the ecology and behavioral biology of local macroinvertebrates such as blue crabs and mud snails; 2) barnacle models as they relate to fouling and the prevention of fouling and bioadhesives; and 3) impacts of xenobiotics on behavior and reproduction. Dr. Rittschoff has also been an avid participant in the Reserve Estuary Live program that uses the internet to bring estuarine programming into the classroom.

A project examining sea level rise and marsh accretion is also being conducted within the Reserve by staff from NOAA's Center for Fisheries and Habitat Research in Beaufort, N.C. and the University of North Carolina – Institute of Marine Science. This work aims to determine if the marshes in Rachel Carson and adjacent coastal waters will keep up with projected sea level rise, and what functional changes may occur in the marsh ecosystem. This work is being headed by Drs Carolyn Currin and Michael Piehler.

A project examining the impact on the Bay Scallop (*Argopecten irradians*) by Cownose Stingray (*Rhinoptera bonasus*) predation is currently occurring within Middle Marsh. This project by University of North Carolina – Institute of Marine Science researchers will provide valuable data needed to managers trying to understand why Bay Scallop numbers have dramatically declined over the past decade.

3.12: Future Research Needs

A large amount of work still remains to be completed at Rachel Carson. This section will detail a few of these projects and potential partners that could assist in making the projects attainable. This is not meant to be an exhaustive list, rather a guide to known knowledge gaps that need to be filled.

A project examining the before and after effects of the management strategy enacted to combat the erosion problem on the east end of Carrot Island is needed. Shoreline stabilization is a high priority for coastal resource managers in the State. This project could provide some valuable data regarding the ecological implications of shoreline stabilization. Partners that could assist in this effort include the N.C. Divisions of Coastal Management and Marine Fisheries, the N.C. Coastal Federation, and the NOAA Beaufort lab.

Horse exclosure experiments need to be conducted on Rachel Carson to quantify the effect the horse population has on native vegetation. This could be done in the upland areas as well as the marshes. This information could help management decide the appropriate number of horses that should be in the herd. This study would also be suitable to include in Reserve education programs. Groups could be taken to the enclosures and visually observe the vegetation in the enclosure compared to that outside. The National Park Service maintains a distinct population of horses on Shackleford Banks. They would be ideal partners to assist in this project.

As noted before, there are several invasive species currently on Rachel Carson that have not been investigated relative to their ecological impacts. This works needs to be done so that management strategies can be developed. The Nature Conservancy and the local marine labs would be ideal candidates for partners in this project.

Results from a research market analysis revealed much interest in continuing the fecal contamination and source tracking work relative to shellfish beds. At current time, shellfish beds are closed anytime total fecal numbers break the established threshold. This policy is slightly problematic as beds are closed at times when the fecal contamination is caused by non-human sources. If rapid source tracking methods can be developed, shellfish beds could be better managed. Closings could only be implemented when the fecal contamination is caused by human sources.

Chapter 4:   Masonboro Island Component

4.1:   Environmental Setting

Masonboro Island is the largest NCNERR component and was designated in 1991. It is located in New Hanover County between the barrier island towns of Wrightsville Beach and Carolina Beach (Figure 4.1). It is bounded by Masonboro Inlet to the north, the Atlantic Ocean to the east, Carolina Beach Inlet to the south, and Masonboro and Myrtle Grove Sounds (part of the Atlantic Intracoastal Waterway) to the west. The city of Wilmington lies approximately five miles to the northwest. Masonboro Island is the largest undisturbed barrier island along the southern part of North Carolina. It is located within the Carolinian biogeographic province. It is approximately 8.4 miles long and encompasses 5,046 acres (20.4 km^2) of subtidal soft bottoms, tidal flats, hard surfaces, salt marshes, shrub thicket, maritime forest, dredge spoil areas, grasslands, ocean beach and sand dunes. Masonboro Island is only accessible by boat. Similar to the Rachel Carson Reserve, private operators provide fee based ferry service to the Reserve property. Most visitors gain access to the Reserve on the sound side of the northern and southern ends of the island where there are large sandy beaches. Most other landings on the sound side within the middle portion of the island are only accessible at or near high tide.

4.2:   Historical Uses

A: Pre-colonial Uses

Prior to English settlement, the area around Masonboro Island was likely used as a hunting ground by Native American Indians. The Eastern U.S. coast including North Carolina was inhabited by Algonkian speaking tribes. However, it is unlikely that Masonboro was permanently inhabited due to the influence of storms and the low relief of the island (Angley 1983).

B: Colonial Uses

There is a very strong possibility that the stretch of beach now known as Masonboro Island was the first portion of the entire American coastline to be seen and described by a European explorer. This initial sighting may well have occurred in March of 1524 when the Italian voyager Giovanni Verrazzano, on an expedition sponsored by Francis I of France, came within view of what is generally believed to have been the lower coastline of present day North Carolina, several miles above the Cape Fear River. During the colonial period Masonboro Island was generally known as Cabbage Inlet Sound, taking its name from the inlet which existed at that time. Cabbage Inlet was located south of today's Masonboro Inlet, just below the mouth of Purviance (now Whiskey) Creek on the opposite side of the sound (Figure 4.1). The mainland shore of Masonboro and Myrtle Grove sounds was sparsely settled during the second quarter of the eighteenth century.

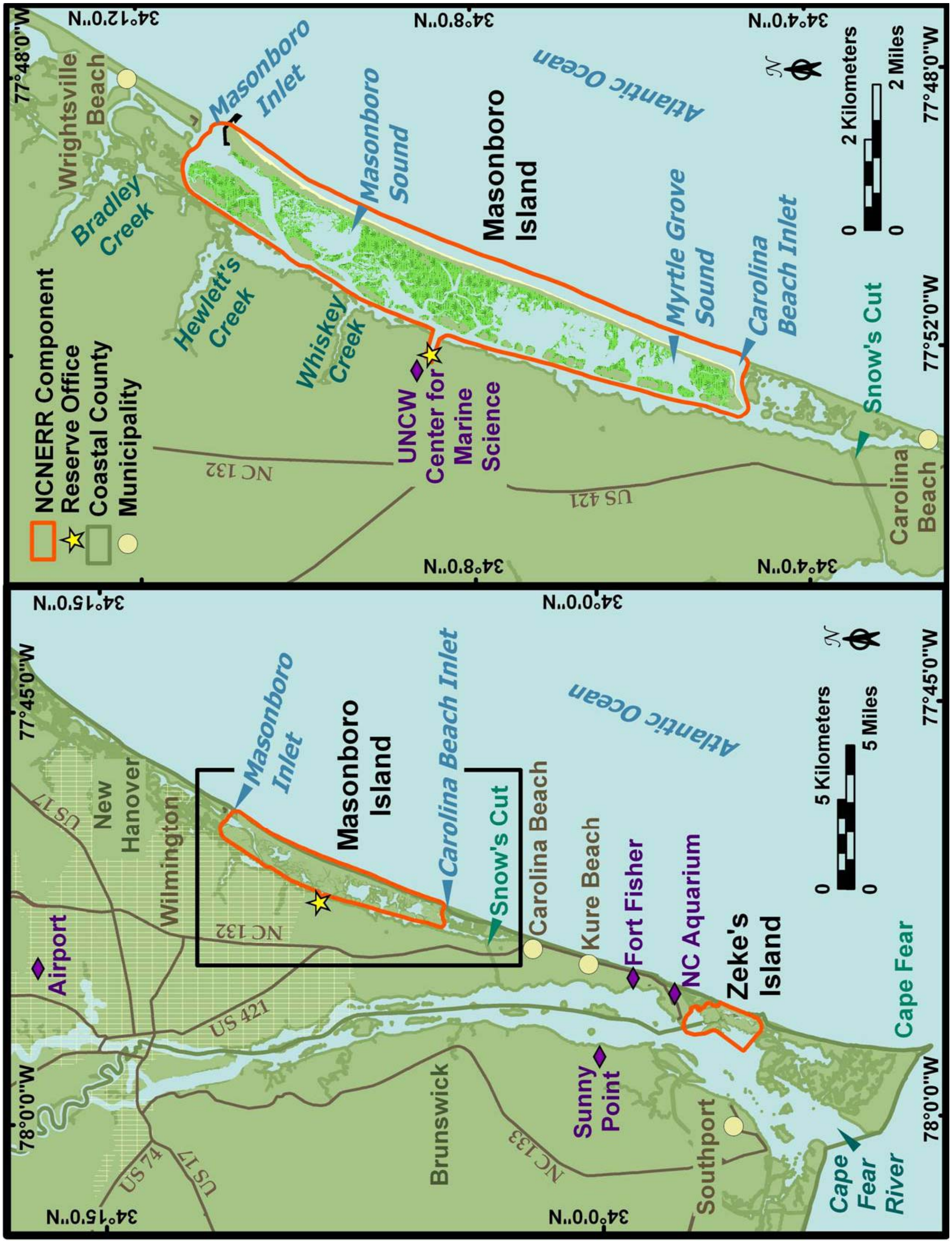


Figure 4.1: Masonboro Island location. The top panel shows a close up of Masonboro Island.

Some of these settlers, generally those of modest means, established permanent residences along the sound, gaining their livelihoods through farming and fishing. Other, more affluent, landowners purchased property on the sound for purposes of speculation or for the establishment of summer homes (Angley 1983).

C: Civil War Uses

Confederate troops were stationed at various points along the mainland shore of Myrtle Grove and Masonboro sounds during the course of the Civil War. Locations include the vicinity of Camp Davis, on the north bank of Hewlett's Creek, and at the state salt works near the mouth of Purviance (Whiskey) Creek (Figure 4.1). Masonboro contained at least seven salt works which operated throughout the war years (Williams and McEachern 1973). These salt works were destroyed by Union forces around 1864.

D: Post Civil War Uses

During the late nineteenth and early twentieth centuries, the mainland side of Masonboro and Myrtle Grove Sounds was settled by farmers, craftsmen, and fishermen. In the fall, mullet were taken in large quantities along the ocean side of the island. Mullet was the most abundant food fish from North Carolina southward and the most important saltwater fish for the post civil war times (Smith 1907). Other important fisheries included flounders, shrimp, clams, and oysters obtained from adjacent sound waters.

4.3: Climate

As part of the SWMP, a weather station has been maintained on a dredge spoil island within the Masonboro Island Reserve since 1994. However, more comprehensive historic climate data may be inferred from the Wilmington area which has a data record going back to 1871.

The nearest National Weather Service network reporting weather station to the Masonboro Island area is located at the Wilmington International Airport (Figure 4.1). Based on National Weather Service data, annual mean temperature for Wilmington from 1871 to 2004 was 62.7 °F (17.1 °C). The coolest temperatures occur in January, with an average daily temperature of 44.8 °F (7.1 °C), and the warmest average daily temperatures, 80.1 °F (26.7 °C), occur in July (Figure 4.2).

During the spring and summer seasons, winds are predominately from the southwest. Fall winds change to northeasterly, while winter winds are primarily from the north. Extratropical storms, known as "nor'easters", generally occur from October to May and are characterized by strong northeast winds which may blow continuously for three or more days (Moorefield 1978).

National Climatic Data Center records indicate the wettest year from 1933-2004 for Wilmington was 1999 with 72.06 inches (183.03 cm) of rainfall. Hurricane Floyd passed through the Wilmington area on September 15, 1999, and September had record rainfall amounts of 23.41 inches (59.46 cm). Average annual rainfall for Wilmington from 1900-2000 was 51.38 inches (130.5 cm). Historically, September is the wettest month and April is the driest month for the Wilmington area. National Climatic Data Center records indicate the driest year from 1933-2004 for the Wilmington area was 1968 with 37.77 inches (95.94 cm) of rainfall (Table 4.1).

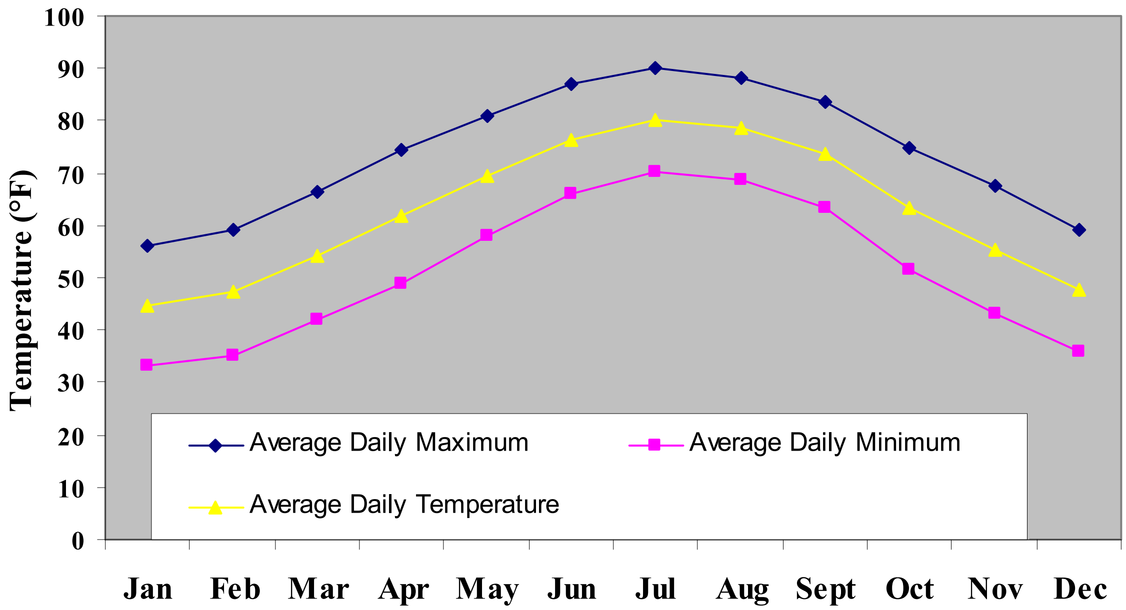


Figure 4.2: Average, minimum and maximum daily temperatures 1871 – 2004 by month for Wilmington, NC. Figure from NOAA-National Climatic Data Center.

Table 4.1: Top ten highest and lowest annual precipitation amounts for Wilmington, N.C. recorded 1933 – 2004

Top 10 highest precipitation amounts 1933 - 2004		
Rank	Precipitation (in)	Date
1	72.06	1999
2	72.05	1946
3	69.95	1947
4	66.65	1989
5	66.2	1992
6	65.63	1966
7	65.11	1995
8	64.42	1996
9	64.2	1998
10	63.95	1945

Top 10 lowest precipitation amounts 1933 - 2004		
Rank	Precipitation (in)	Date
1	37.77	1968
2	37.98	2001
3	39.06	1941
4	40.89	1954
5	42.16	1967
6	43.18	1933
7	43.7	1978
8	43.89	1956
9	44.02	1985
10	44.38	1981
Data from NOAA-National Climatic Data Center		

Table 4.2 shows the named tropical systems that have passed within 65 nm of Masonboro Island of the past 50 years. Notable storms include Bertha and Fran in 1996 which caused extensive damage to the Wilmington area. In 1999 Hurricane Floyd passed directly over Masonboro Island before moving North. The rainfall associated with Floyd led to extensive flood damage in the coastal plain region of North Carolina. More recently, Hurricane Ophelia passed just offshore in September of 2005 bringing large amounts of beach front erosion and large amounts of rainfall. Nor'Easters do not get named like tropical systems, but are usually denoted by the month or significant calendar event and year in which they occur (*i.e.* the Halloween storm of 1991). Several Nor'Easters have also impacted the region since 1956.

Table 4.2: Tropical storms passing within 65nm of Masonboro Island since 1956

Storm	Date	Name	Wind (kts)	Minimum Pressure (mb)	Classification
1	September 1956	Flossy	35		Extratropical
2	September 1958	Helene	115	938	Category 4 hurricane
3	July 1960	Brenda	50		Tropical storm
4	September 1960	Donna	95	958	Category 2 hurricane
5	September 1961	Not Named	35		Tropical depression
6	August 1962	Alma	45	1002	Tropical storm
7	September 1964	Dora	45		Tropical storm
8	June 1966	Alma	40	997	Tropical storm
9	June 1968	Abby	25		Tropical depression
10	October 1968	Gladys	75		Category 1 hurricane
11	August 1970	Not Named	30	1013	Tropical depression
12	August 1971	Doria	50	998	Tropical storm
13	October 1971	Ginger	65	984	Category 1 hurricane
14	June 1972	Agnes	40	988	Tropical storm
15	June 1975	Amy	30	1006	Tropical depression
16	October 1975	Hallie	45	1002	Tropical storm
17	September 1977	Clara	25	1011	Tropical depression
18	August 1981	Dennis	55	998	Tropical storm
19	June 1982	Subtropical 1	60	992	Subtropical storm
20	September 1984	Diana	115	949	Category 4 hurricane
21	November 1985	Kate	45	996	Tropical storm
22	August 1987	Arlene	10	1016	Tropical low
23	June 1995	Allison	40	995	Extratropical
24	June 1996	Arthur	40	1005	Tropical storm
25	July 1996	Bertha	90	974	Category 2 hurricane
26	September 1996	Fran	100	954	Category 3 hurricane
27	October 1996	Josephine	45	988	Extratropical
28	August 1998	Bonnie	100	962	Category 3 hurricane
29	September 1998	Earl	50	995	Extratropical
30	September 1999	Floyd	90	950	Category 2 hurricane
31	October 1999	Irene	80	976	Category 1 hurricane
32	June 2001	Allison	25	1006	Subtropical depression
33	October 2002	Kyle	35	1011	Tropical storm
34	August 2004	Bonnie	25	1008	Tropical depression
35	August 2004	Charley	65	988	Category 1 hurricane
36	September 2005	Ophelia	75	979	Category 1 hurricane
Data from the NOAA – Coastal Services Center					

Snow and sleet are rare for this area due to the warming effect of the ocean in winter, but do occasionally occur.

4.4: Geological Processes

Masonboro Island is part of a barrier island complex formed offshore with the time frame being speculative (Atkinson et al. 1998). The genesis of the original island is thought to have occurred by mainland beach detachment (Hosier and Cleary 1977a and 1977b). According to Hoyt (1967) separation of the barrier island from the mainland occurred during the last 5,000 years when the Holocene sea rise slowed down. Dune ridges formed along a seashore that was some distance seaward of the present coast. The rising sea then isolated the dune ridges from the mainland forming barrier islands that were then translated landward under the influence of rising sea level. Island "migration" is still occurring as evidenced by formed sound-side peat and shell deposits being exposed on the ocean beaches of many extant barrier islands (Godfrey and Godfrey 1976).

The Masonboro Island component consists of Recent (less than ~11,550 years old) and Pleistocene (~1.8 million to ~11,550 years before present) sediments that are part of the Pamlico Terrace located on the eastern edge of the North Carolina coastal plain (Atkinson et al. 1998). The upland areas include 500+ acres of natural grasslands, dunes and woody vegetated areas and 166 acres of dredge material islands (Atkinson, et. al. 1998). The remaining 4300+ acres are estuarine areas including marshes and tidal flats (Atkinson et al. 1998).

The soils of Masonboro are classified as Entisols (Atkinson et al. 1998). The grassland areas along the ocean side of Masonboro as well as the dredge spoil islands are underlain by well drained Newhan series (Soil Conservation Service 1977). The dredge spoil islands within Masonboro Island Reserve were created in the late 1920s, when materials from the waterway construction were placed over portions of the marsh and tidal flats (Cleary and Hosier 1995). The substrate for shrub thicket and maritime forest is associated with poorly drained Duckston series, while the marshes and tidal flats are associated with the Carteret series (Soil Conservation Service 1977).

4.5: Hydrology and Water Quality

A: Ocean Side

a: Hydrology

The waters surrounding Masonboro Island are categorized as marine waters of the outer open coast or estuarine waters of the inner back bay (NOAA 1984). The mean tidal range of the open ocean at Masonboro Inlet is 3.8 ft (1.1 m) with spring tides averaging 4.5 ft (1.4 m) and average wave height is 2.7 ft (0.8 m) (Cleary and Hosier 1995). The hydrology around Masonboro Island has been significantly altered by humans. The stabilization of Masonboro Inlet, the creation of Carolina Beach Inlet, as well as the opening of Snow's Cut between the Intracoastal Waterway and the Cape Fear River has impacted sediment transport and hydrology of areas surrounding Masonboro Island.

The north end of the island is bounded by Masonboro Inlet, which has migrated over 4,000 feet (1219 m) since 1909 (Seabergh and Thomas 2002). Masonboro Inlet appears on historical charts from 1733, documenting the opening of the inlet in the in the early 1700s two kilometers north of its present location (Cleary and Marden 2001). Fifteen years after the completion of the Atlantic Intracoastal Waterway in 1932, the inlet's channel was artificially relocated at the southern end of a barrier spit extending northward from Masonboro Island (Cleary and Marden 2001). In 1950, a navigation project was proposed, calling for a 14 ft (4.3 m) by 400 ft (122 m) channel across the ebb-tidal delta, dual jetties and a series of access channels to the Intracoastal Waterway (Cleary and Marden 2001). In June 1966, the northern weir jetty was completed after difficulties were encountered trying to maintain the channel by dredging alone (Cleary and Marden 2001). The south jetty was completed in 1981 after several attempts to relocate the inlet away from the north jetty (Cleary and Marden 2001).

Inlet modifications have substantial impacts on the adjacent barrier islands (Cleary and Marden 2001). The Masonboro Island shoreline south of the jetty has built up as much as 295 ft (90 m), while the remainder of the island has retreated as much as 426 ft (130 m) over the past 20 years (Cleary and Marden 2001). Historic charts show the presence of Sugarloaf Inlet near the vicinity of Carolina Beach Inlet in 1882, and though the exact date is unknown, it is presumed that this inlet closed prior to 1900 (Cleary and Hosier 1995). After the closure of Sugarloaf Inlet and prior to 1952, Masonboro Island did not exist as a separate island, but was connected to present-day Carolina Beach (itself having been separated from the mainland in the 1930s by Snow's Cut). The artificial opening of Carolina Beach Inlet in 1952 for the private interests of local fishing enthusiasts afforded easier ocean access for boaters in the lower Cape Fear River region and consequently improved water quality in Myrtle Grove Sound (Jarrett 2000).

Masonboro Island also experiences overwash in the low relief and narrow section of the barrier island. Dunes on Masonboro are generally less than 13 ft (4 m) in elevation and the most of the dunes are located on the northern portion of the island (Cleary and Hosier 1995). A few isolated dunes once rose above 20 ft (6 m) and are visible on older topographic maps (Cleary and Hosier 1995), however the series of storms in the late 1990s dramatically decreased the height of most of the dunes on Masonboro.

Erosion occurring on Masonboro Island within the past several decades can be attributed to reduced sediment supply from inlet alterations by man and frequent storm events (Cleary and Hosier 1995). U.S. Army Corps of Engineers studies indicate that the barrier spit was relatively stable before the opening of Carolina Beach Inlet and the construction of Masonboro Inlet jetties (Cleary and Marden 2001). After the opening of Carolina Beach Inlet, Masonboro Island and Carolina Beach both began to rapidly erode (Cleary and Marden 2001). The increased ability for the ebb tidal delta of Carolina Beach Inlet to retain sediments has adversely affected Masonboro Island (Cleary and Marden 2001).

Both inlets are federally maintained navigational channels. The north jetty at Masonboro Inlet is designed to allow sediment from the predominant southbound littoral current to enter the inlet, where it is retained in a deposition basin. The south jetty effectively prevents almost all north bound littoral sand transport from Masonboro Island from entering the inlet (Jarrett 2000). Sediments from Masonboro Inlet are periodically extracted and used to renourish both Masonboro Island and Wrightsville Beach. According to the sediment budget analysis conducted in 1982 (used to inform current renourishment activities), the estimated amount of sand bypassing needed to offset project induced erosion is 125,000 cubic yards/year (95,569

m^3/year) to Masonboro Island (Jarret 2000). Sediments extracted from Carolina Beach Inlet are used to renourish Carolina Beach only. The southern third of the island does not receive beach nourishment and has suffered a sediment deficit of approximately 3.2 million cubic yards (2,446,575 m^3) for the period 1969 to 1999 and remains in a sediment starved condition. While the area immediately south of the southern jetty at Masonboro Inlet is stable, the main portion of the island has experienced a net deficit in the supply of littoral material since 1969 (Jarrett 2000).

b: Water Quality

Ocean-side water quality monitoring is conducted by two entities, the Coastal Ocean Research and Monitoring Program (www.cormp.org) and the Department of Environmental Health Shellfish Sanitation and Recreational Water Quality Section. The Coastal Ocean Research and Monitoring Program is a collaborative program of NOAA, the University of North Carolina Wilmington, North Carolina State University and the University of South Carolina. This program monitors near shore ocean conditions and water quality parameters near Masonboro Island (Figure 4.3). These monitoring stations provide valuable data which can be used to infer conditions in the region offshore of Masonboro Island.

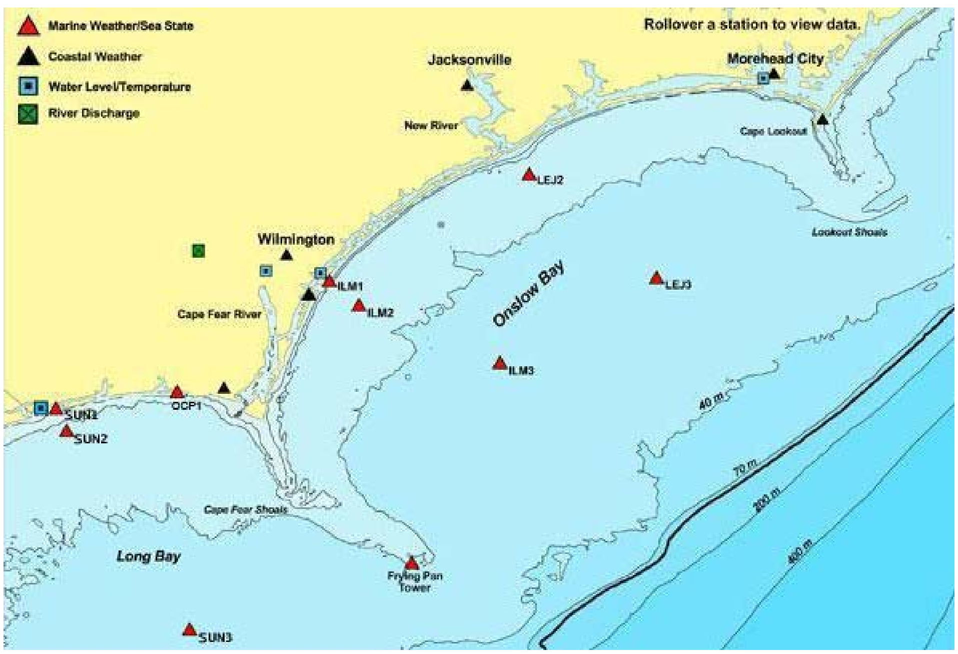


Figure 4.3: Coastal Ocean Research and Monitoring Program sampling stations near Masonboro Island.

Based on data from the Coastal Ocean Research and Monitoring Program, the areas of Onslow and Long Bay have good water quality. The area around the mouth of the Cape Fear River has occasional water quality declines associated with runoff events but these typically dissipate once the runoff event subsides.

The N.C. Department of Environmental Health Shellfish Sanitation and Recreational Water Quality Section monitors for enterococcus bacteria (an indicator organism whose presence is correlated with that of others that can cause illness in humans) to determine if swimming advisories should be posted at several locations in and around Masonboro Island. Limits for enterococcus are based on the level of use a particular beach receives. A Tier 1 area is defined as receiving daily use during swimming season (April – September). Tier 1 beaches shall not exceed either: (1) A geometric mean of 35 enterococci per 100 ml of water, that includes a minimum of at least five samples collected within 30 days; or (2) A single sample of 104 enterococci per 100 ml of water. A Tier 2 area is defined as receiving on average three days

Figure 4.4: Water quality monitoring locations at Masonboro Island.

of use per week during swimming season. The enterococcus level in a Tier 2 swimming area shall not exceed a single sample of 276 enterococci per 100 ml of water.

There are no beach side (Tier 1) sites on Masonboro Island. Compared to other area beaches, Masonboro is not as accessible to the general public and the island is not developed. These factors combine to limit the pollution sources and usership of the Island thus preventing it from qualifying for sampling by the water quality section. However, there are two Tier 1 sites near Masonboro located at Carolina Beach (Site S-21) and Wrightsville Beach (Site S-22A) (Figure 4.4) that provide information regarding the ocean-side water quality for Masonboro Island. Based on the data available for these locations, the water quality on the ocean-side of Masonboro Island is good relative to fecal bacteria. The average enterococcus bacteria concentration for Site S-21 (2003-2006) was 11.3 enterococci per 100 ml water and Site S-22A (2003-2006) was 12.4 enterococci per 100 ml water.

B: Sound Side

a: Hydrology

Masonboro and Myrtle Grove Sounds are included in the Cape Fear River Basin by the North Carolina Division of Water Quality (Figure 4.5). In reality, the only real connection between the Sounds and the Cape Fear River is the artificially created Snow's Cut (Figure 4.1). The estuarine waters of Masonboro and Myrtle Grove Sounds have restricted access to the ocean through Masonboro Inlet, Carolina Beach Inlet and occasional overwash. Considerable freshwater influx occurs through mainland tidal creeks, surface runoff, ground water seepage (from the island and mainland), and direct precipitation (NOAA 1984). The hydrology in the sounds is dominated by the tidal exchange through Masonboro and Carolina Beach Inlet, but tidal flushing is not complete, particularly at the midpoint region between the inlets (Zullo 1984). Two major tidal creeks, Hewletts and Whiskey, drain into the Intracoastal Waterway adjacent of the northern portions of Masonboro Island component (Figure 4.4). Field observations in the vicinity of Snow's Cut indicate variably located tide lines separating the higher salinity oceanic waters from the darker, tannin stained, low salinity riverine waters. Although the waters of the Cape Fear do not significantly influence the Masonboro Island Estuary (United States Army Corps of Engineers 1980), the southern portion of Masonboro and the adjacent marshes are affected by a small amount of water that comes through Snow's Cut that does not pass through Carolina Beach Inlet.

b: Water Quality

The absence of development on Masonboro Island coupled with tidal flushing result in generally very good to excellent water quality in Masonboro Sound. However, low to moderate levels of bacteria are contributed from sewage spills, septic tank effluents and surface runoff from portions of New Hanover County that drain into the sound via mainland creeks. The water quality parameters for Hewletts and Whiskey Creeks were monitored as part of the New Hanover County Tidal Creeks Program, facilitated though the University of North Carolina Wilmington's Center for Marine Science, Aquatic Ecology Laboratory until 2007 when this project was completed. Hewletts Creek has seen repeated sewer spills, including incidents in 1992, 1993, and 1994 which resulted in over 650,000 gallons (2,460,517 L) of effluent entering the creek.

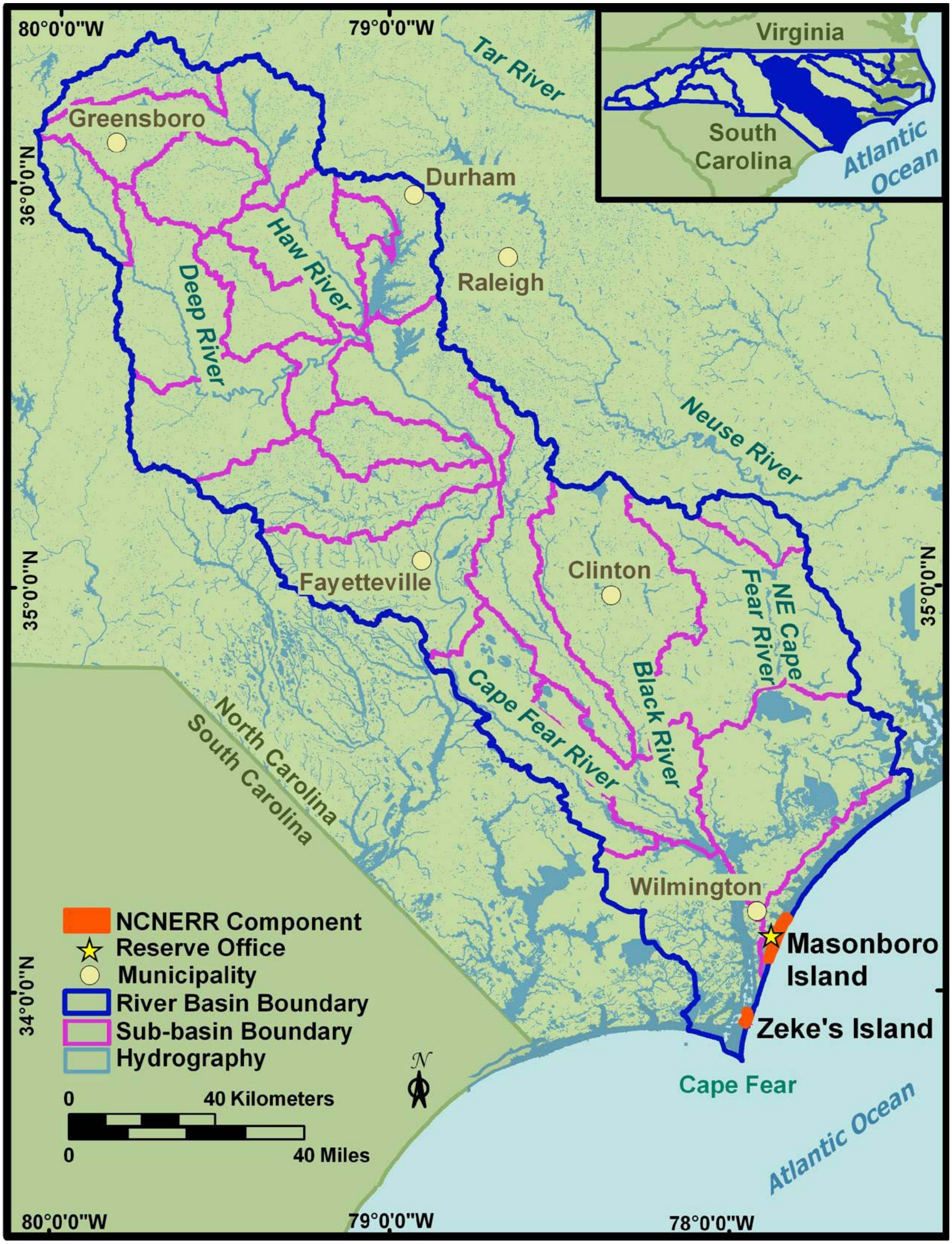


Figure 4.5: Cape Fear River Basin map.

More recently, spills in 2004, 2005, and 2006 introduced more than 4 million gallons (15,141,647 L) of raw sewage into Hewletts (McGrath 2006). These events resulted in algal bloom events on the creek and incidents of hypoxia. The latter led to fish kills and some duck mortality (Mallin et al. 2006). Fecal coliform bacteria concentrations (within the water column and sediment), nutrient concentrations, and algal blooms were also dramatically increased following the sewage spill (Mallin et al. 2006). Regulatory agencies banned swimming in the Intracoastal Waterway for two weeks following the sewage spill and banned swimming within Hewletts Creek for the remainder of the summer (Mallin et al. 2006). Hewletts Creek and surrounding areas of the waterway were closed to shellfish harvesting after the sewage spill as well (Mallin et al. 2006). Tropical storm Ernesto resulted in 18,000 gallons (68,137 L) of sewage being spilled into the creek (Gannon 2006a and 2006b). Despite such incidents, the creek has no persistent dissolved oxygen, turbidity, or algal bloom problems (Mallin et al. 2006). However, some sections of Hewletts Creek will be added to the North Carolina 303(d) list of impaired waters (North Carolina Division of Water Quality 2005).

The water quality stations in Whiskey Creek monitored as part of the New Hanover Tidal Creeks Program were considered good quality, violating the North Carolina State Standards in less than 10% of all samples for dissolved oxygen, turbidity and chlorophyll *a* concentrations for the 2004-2005 monitoring period (Mallin et al. 2006). The station at the mouth of Whiskey Creek experienced high levels of nutrient concentrations during 2004-2005. This site had the highest levels of phosphate, ammonium and nitrate compared to all other creek mouth stations sampled as part of the New Hanover County Tidal Creeks Program (Mallin et al. 2006). Whiskey Creek is currently closed to shellfish harvesting and will also be added to the state's 303(d) list of impaired waters (North Carolina Division of Water Quality 2005).

The North Carolina Department of Natural Resources, Division of Water Quality produces a Basinwide Water Quality Plan for each river basin in North Carolina. The Cape Fear River Basinwide Plan lists the waters of Masonboro Sound as part of the 03-06-24 Subbasin. Within the portion of this subbasin near Masonboro Island, one station is monitored for macroinvertebrates (BB299), and one station is monitored for ambient water quality (BA730). The macroinvertebrate station was located within Hewletts Creek (Figure 4.4) and was sampled in 2003. It was found to be "supporting" for aquatic life, with the result listed as "moderate stress" with possible stressors of fecal coliform bacteria (North Carolina Division of Water Quality 2005). The ambient monitoring station was located within Masonboro Sound north of Carolina Beach Inlet (Figure 4.4). This site was found to be "supporting" for both aquatic life and recreational use, but "impaired" and conditionally approved for shellfish harvesting. All waters within this subbasin are listed as "impaired" for the fish consumption category because of fish consumption advice that applies to the entire basin (North Carolina Division of Water Quality 2005). All waters within this basin are listed as "supporting" for the water supply category. Masonboro Sound is considered an Outstanding Water Resource Area by the North Carolina Division of Water Quality. Segments of Masonboro Sound on the mainland side, near tidal creeks and marinas are listed as "impaired" for shellfish harvesting and are classified as prohibited or conditionally approved open (North Carolina Division of Water Quality 2005).

Recreational water quality testing is conducted at three sites in and around Masonboro Island by the North Carolina Department of Environmental Health Recreational Water Quality Program (Figure 4.4). Site S46A is located off the southern end of Masonboro, near Carolina Beach Inlet. Site S47A is within the Intracoastal Waterway across from Whiskey Creek and near the NCNERR Research Creek monitoring area. Site S48 is located in an area called Masonboro

Channel, between the northern end of Masonboro and the most northern dredge spoil island within the Reserve component. Based on the data available on the Recreational Water Quality Program there were no swimming advisories for site S46A and S48. Site S47A had one swimming advisory in September 2004. The average enterococcus bacteria concentrations for Sites S46A (2004-2006), S47A (2004-2006) and S48 (2003-2006) were 13.14, 28.30, and 20.38 enterococci per 100 ml water respectively. Sites S46A and S47A experienced the highest concentrations during this monitoring period in September 2004; S46A=137 enterococci, S47A=782 enterococci per 100 ml water. These high values were obtained after nearly two inches of rain had fallen the prior two days (precipitation data from NCNERR SWMP). The highest value at site S48, 75 enterococci per 100 ml, also occurred during September 2004. Only 4% of samples for this period had concentrations over 20 enterococci per 100 ml. This is not surprising given that S46A and S48 are in close proximity to inlets and that the waters near S47A often have swift currents with tidal cycles. Thus, pollutants in the area are rapidly flushed and high concentrations of pollutants are probable for only short durations after periods of heavy rain.

Staff of NCNERR maintains two SWMP stations on Masonboro Island. The locations of these sampling locations are shown in Figure 4.4. The Research Creek site has been in continuous operation since 1994, Loosin Creek since 2002. Both stations are equipped with continuously monitored water quality instruments made by Yellow Springs Instruments that measure: dissolved oxygen, pH, temperature, conductivity and turbidity. The Research Creek site is equipped with satellite telemetry that beams the data in near real time to the internet through NOAA's Centralized Data Management Office. These locations have also been sampled monthly for nutrient (NH_4^+, NO_3^- and PO_4^{-3}) and chlorophyll *a* concentrations since 2002. The water quality within Masonboro Island is typically good. The criteria for a "good" rating are that N.C. State standards are not exceeded in more than 10% of all samples (see (North Carolina Division of Water Quality 2004) for a full list of state water quality standards). A "fair" rating has samples exceeding N.C. State standards in 11-25% of measurements, and a "poor" rating has samples exceeding the N.C. State standard more than 25% of the time. Table 4.3 provides the high, low and average for the measured water quality parameters at Masonboro Island.

Table 4.3: SWMP water quality data from
Masonboro Island 2002-2006

	Loosin Creek data	Research Creek Data
Parameter	**Range, Average**	**Range, Average**
Dissolved O_2 (%)	5.2 – 196.9, 95	0.6 – 211.5, 90.4
pH	6.3 – 9.2, 8.1	7.1 – 10.8, 8.0
Conductivity(mS/cm)	23.68 – 55.69, 47.93	16.53 – 54.67, 42.64
Salinity (psu)	14.3 – 37, 31.2	9.6 – 36.1, 27.4
Turbidity (NTU)	0 – 1000, 26	0 – 1000, 32
NH_4^+ (mg/l)	BDL – 0.63	BDL – 3.3
NO_3^- (mg/l)	BDL – 0.15	BDL – 0.29
PO_4^{-3} (mg/l)	BDL – 0.16	BDL – 0.049
Chlorophyll *a* (μg/l)	BDL – 9.29	BDL – 107.56
BDL = Below Detection Limit		

Table 4.3 shows that nutrient concentration levels around Masonboro Island are usually very low. This is consistent with the lack of development and scarce sources of pollution on the island. Salinity is usually quite high validating the argument that the waters around Masonboro

Island are hydrological separate from major fresh water sources. Salinity from Loosin Creek is on average higher than that from Research Creek. This is consistent with Research Creek being farther away from the oceanic inlet than Loosin Creek. Chlorophyll *a* levels from both sampling stations are typical for the region. The Chlorophyll *a* levels were much higher in Research Creek compared to Loosin Creek. Although we currently do not have any flow data for the two sampling locations, the geomorphology of the creeks suggest that Loosin Creek has higher flow rates compared to Research Creek. Loosin Creek is within 1 mile (1.6 km) of the inlet and is located in a wide mouthed open tidal creek. Consequently, flow at Loosin Creek is likely quite high. Research Creek is located much farther from the inlet (~ 3 miles (4.8 km)) and is in a very narrow sheltered tidal creek with a sand bar constricted mouth. Consequently, flow at Research Creek is likely much slower than that at Loosin Creek. The lower flow gives algae more time to assimilate nutrients and grow before being flushed out of the area accounting for the higher Chlorophyll *a* values. Figure 4.6 shows the average annual temperature, salinity, dissolved oxygen, and turbidity measured at the Masonboro SWMP stations. Combining flow measurements with the water quality data is a research need for the Masonboro component.

The only parameter that shows any major deviation at both stations since 1994 is turbidity. Turbidity ranged from 15 to 55 NTU at Research Creek, and from 10 to 50 NTU at Loosin Creek. Turbidity was the highest at Research Creek and lowest at Loosin Creek during 2004. The year with the highest turbidity at Loosin Creek occurred in 2006. Two tropical systems impacted the area in 2004, tropical storm Bonnie, and hurricane Charley both in late summer (Table 4.2). In addition, there were strong winds and heavy rain in the Wilmington area during August 2004 as a result of Tropical Storm Gaston near Charleston, SC. The wind and rain from these storms were most likely major contributing factors for the high turbidity average at Research Creek during 2004. The fact that Research Creek and Loosin Creek responded differently during this time fame supports the idea that they are in very different hydrologic environments. The rapid tidal flushing that occurs at Loosin Creek, due to its proximity to the inlet, likely reduced the effect of the tropical systems on turbidity values during 2004 compared to Research Creek.

Figure 4.7 shows the average nutrient (NO_3^-, NH_4^+, PO_4^{-3}) concentrations and Chlorophyll *a* values for the two SWMP stations found at Masonboro Island. Both stations show a large increase (over 500 $\mu g\ l^{-1}$) in ammonium (NH_4^+) concentrations in August through December 2002. NH_4^+ concentrations throughout the rest of the time period become episodically elevated especially in late summer but never approach the high values seen in fall 2002. Nitrate (NO_3^-) levels were usually low (< 50 $\mu g\ l^{-1}$), but did increase at both stations during November 2002 and August 2004. Since these peaks occurred at both stations at the same time, it suggests a single large scale causative agent as opposed to separate local scale events. Phosphate (PO_4^{-3}) levels were extremely low throughout the entire dataset. Overall dissolved inorganic nitrogen (NH_4^+ and NO_3^-) to Phosphorus levels for both stations was 30. Compared to the Redfield ratio 16 (Redfield 1958), our data suggest the waters around Masonboro Island are enriched in nitrogen. Chlorophyll *a* levels were similar for both stations. Maximum Chlorophyll *a* values were typically observed in late summer at both stations. The late summer Chlorophyll *a* maximum is most likely due to the increased availability of NH_4^+ during this time and also to the increased temperatures. Chlorophyll *a* values were usually lowest during winter. There was one unusual Chlorophyll *a* peak at Research Creek in February 2003. This peak occurred about 1 month after a large nutrient pulse containing NH_4^+, NO_3^- and PO_4^{-3} (Figure 4.7). Chlorophyll levels at the Masonboro SWMP stations are correlated with both dissolved inorganic nitrogen

(NO_3^- and NH_4^+ combined) and PO_4^{-3} ($p < 0.05$). Thus, the large pulse of nutrients that occurred in fall 2002 likely caused the observed Chlorophyll *a* peak in February 2003.

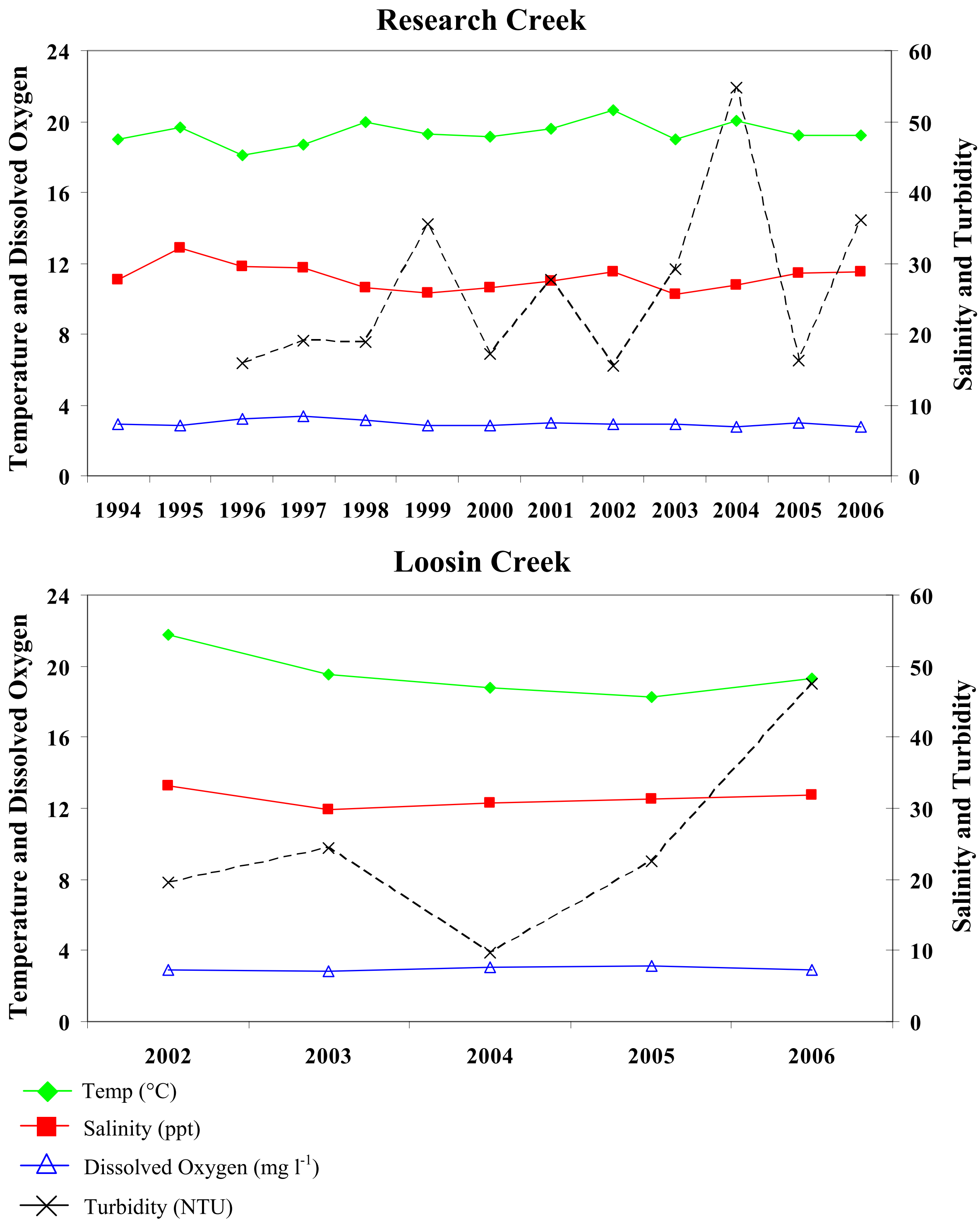


Figure 4.6: Yearly averaged physical-chemical SWMP data from Masonboro Island.

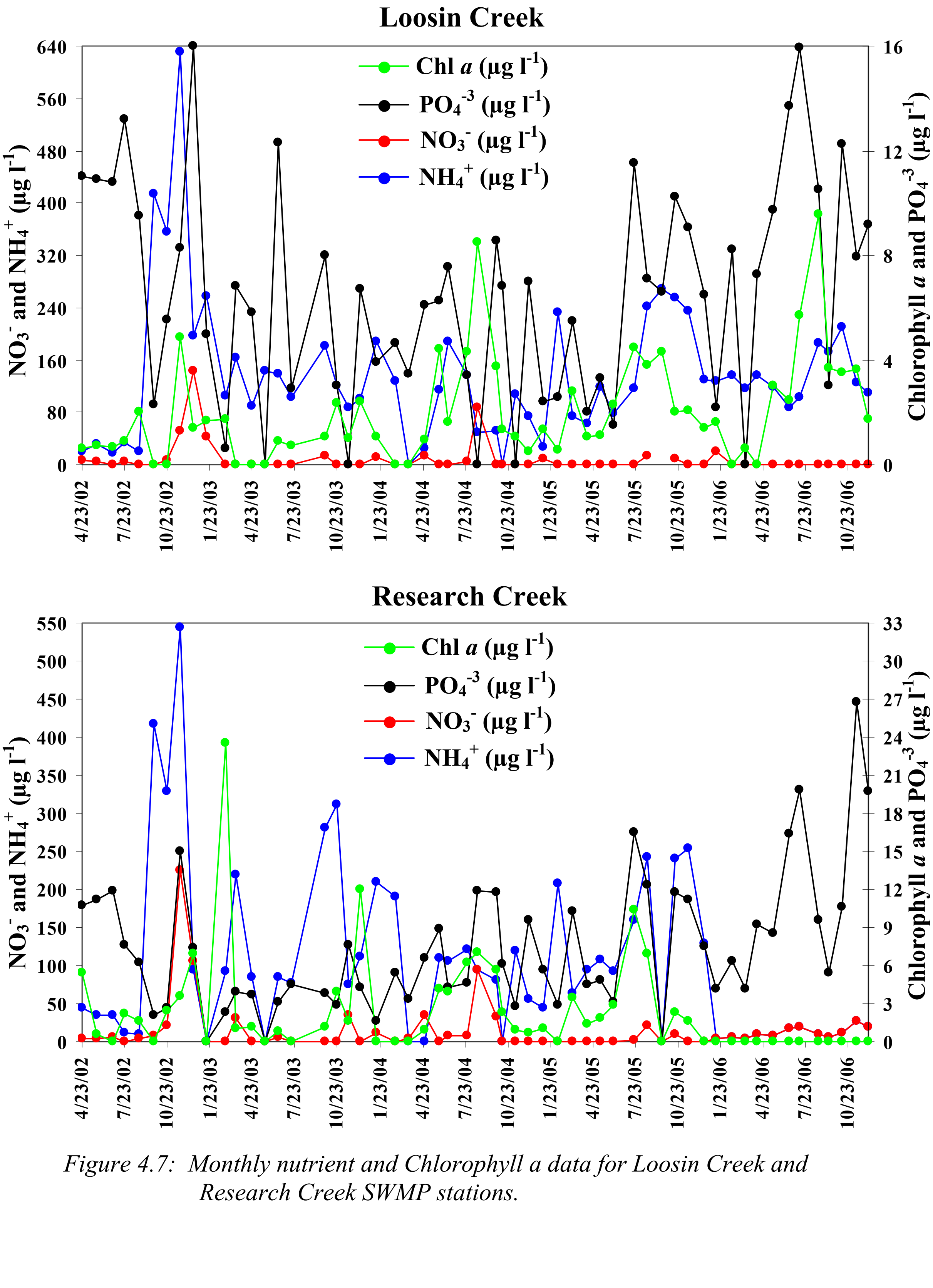


Figure 4.7: Monthly nutrient and Chlorophyll a data for Loosin Creek and Research Creek SWMP stations.

4.6: Habitat Types

A primary objective of SWMP Phase 3 is to evaluate changes over time in estuarine habitats and coastal land cover. To accomplish this, the types and locations of habitats within the Reserve must be periodically quantified. The habitat types of Masonboro Island were initially characterized in 1994. This effort used a very general classification system that only broke habitats down into very broad categories. These habitat types included subtidal soft bottoms, tidal flats, hard surfaces, salt marshes, shrub thicket, maritime forest, dredge spoil areas, grasslands, ocean beach and sand dunes (Table 4.4). Figure 4.8 shows the resultant map from this effort. However, this assessment provided only minimal information regarding habitat types and function. To more accurately and methodologically account for the various habitat types within the Reserve components, in 2005 NCNERR participated as a pilot Reserve for the NERRS habitat and land use classification system. This effort categorized the habitats within the Reserves using a much improved classification system (Appendix 4).

Table 4.4: Masonboro Island 1994 habitat classifications

Habitat	Description
Subtidal softbottom	Open sand or mud flats that never get exposed at low tide.
Tidal creeks	Open water feeder creeks through the marshes and across tidal flats.
Submerged aquatic plant beds	Subtidal areas that are primary habitat for bay scallops and associated species.
Intertidal mud and sand flats	Open sand or mud flats that are submerged at high tide and exposed at low tide.
Salt marshes	Low and high fringing areas that are persistently wet.
Rock jetty	Allocated on the north end of the island.
Maritime shrub thicket	Shrub areas on the upland island areas.
Evergreen maritime forest	Forested areas in the central portion of the island.
Dredge material areas	Areas along the waterway ranging in successional communities from open sand to herb dominated to woody vegetation.
Dunes	Upland areas stabilized by grasses, natural barrier to waves.
Ocean beach	Intertidal areas of sandy beach stretching the length of the island.

The updated habitat map for the Masonboro Island component is presented at the subclass level in Figure 4.9. Areal statistics for habitat occurrence were calculated from the digital classification data and are provided as acreage and the percentage of total acres mapped for each habitat subclass (Table 4.5). Subtidal areas were not included in this assessment. Visual observations were made during field surveys to document predominant plant species for each habitat subclass. These data provide a baseline framework for conducting more in-depth inventories of vegetation composition and conditions. Habitat subclasses at Masonboro Island are described in the following paragraphs, with representative photographs presented in Appendix 4.

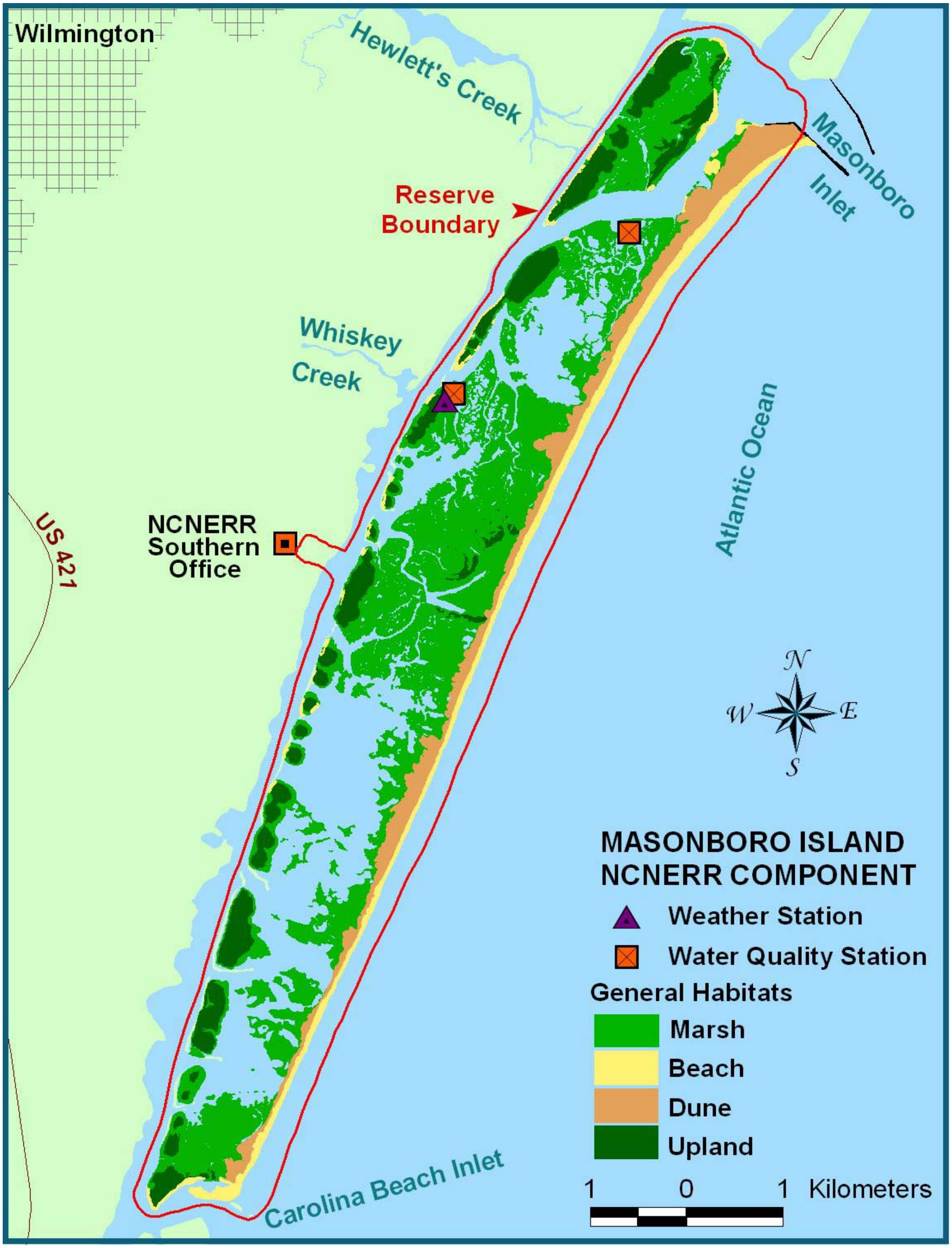


Figure 4.8: Habitat map from 1994 for Masonboro Island.

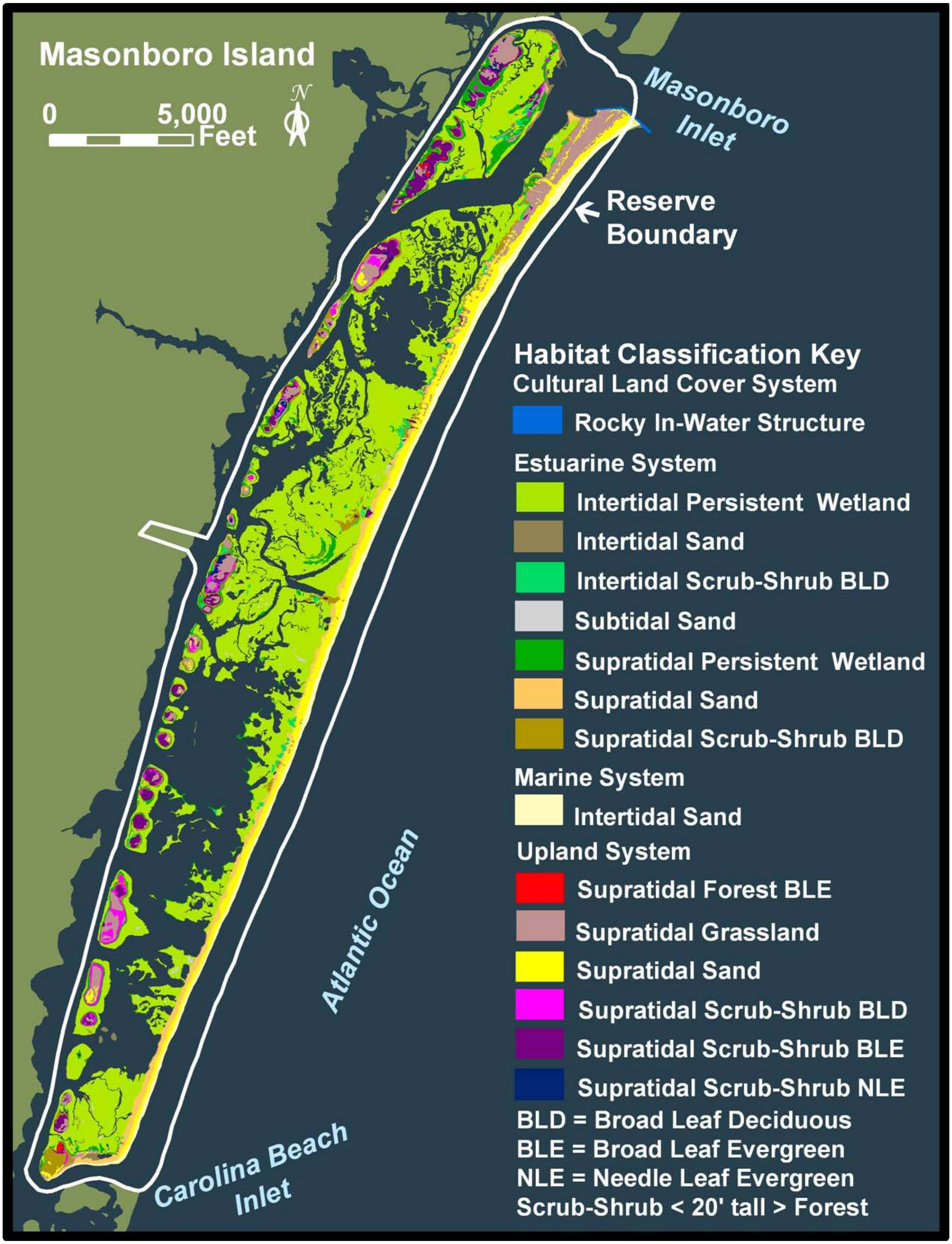


Figure 4.9: Masonboro Island 2004 habitat classification presented at the subclass level.

Table 4.5: Masonboro Island 2004 habitat classifications areal statistics

Habitat Subclass	Area (Acres)	% of Total
Estuarine Intertidal Persistant Wetland	1510.58	58.43
Upland Supratidal Sand	202.39	7.83
Upland Supratidal Grassland	197.49	7.64
Marine Intertidal Sand	133.44	5.16
Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous	122.45	4.74
Upland Supratidal Scrub-Shrub Broad Leaf Evergreen	108.51	4.20
Estuarine Supratidal Persistant Wetland	105.16	4.07
Estuarine Supratidal Sand	97.63	3.78
Estuarine Intertidal Scrub-Shrub Broad Leaf Deciduous	46.70	1.81
Estuarine Intertidal Sand	36.89	1.43
Upland Supratidal Scrub-Shrub Needle Leaf Evergreen	11.63	0.45
Estuarine Subtidal Sand	7.68	0.30
Upland Forest Broad Leaf Evergreen	3.17	0.12
CLC Rocky in Water Structure	1.67	0.06
Total Mapped Habitat Area	**2,585.38***	**100**
* Subtidal areas not included		

- The most dominant habitat subclass within the Masonboro Island Component was Estuarine Intertidal Persistant Wetland, comprising over 58% and over 1500 acres of total habitat. This subclass, commonly known as the salt marsh was located extensively along the sound side edges of Masonboro Island as well as between the island and dredge spoil island areas. The dominant plant species is Smooth Cordgrass (*Spartina alterniflora)*.

- The second largest subclass was Upland Supratidal Sand, with 202 acres and 8% of total habitat. The majority was located adjacent to the supratidal areas of open beach along the eastern shore of Masonboro Island. This subclass, commonly known as "Sand Dunes", includes Sea Oats (*Uniola paniculata*) and other grass species. These are open areas, with $\leq$ 30% vegetative cover.

- Upland Grassland, covering 200 acres and 8% of total habitat, was found in the interior portions of northern and southern Masonboro Island and on the dredge spoil islands to the west. These grassland areas are inhabited by a mixed community of perennial beach grasses such as Salt Meadow Hay (*Spartina patens)*, Sea Oats (*Uniola paniculata*), Inland Saltgrass (*Distichlis spicata*) and several species of *Panicum.*

- The fourth largest subclass was Marine Intertidal Sand, 133 acres (5% of total habitat) of beach along eastern Masonboro Island. This is the largest amount of Atlantic Ocean beach within the NCNERR components.
- The following subclasses made up between 3 - 5% of total habitat and covered between 90-125 acres each (listed in decreasing order): Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous containing Sea Ox-eye (*Borrichia frutescens*); Upland Supratidal Scrub-Shrub Broad Leaf Evergreen hosting a mix of Yaupon (*Ilex vomitoria*), Wax Myrtle (*Morella cerifera* or *Myrica cerifera*), and Laurel Oak (*Quercus laurifolia*); Estuarine Supratidal Persistant Wetland with salt meadow hay (*Spartina patens*), Inland Saltgrass (*Distichlis spicata*), and Black Needle Rush (*Juncus roemarianus*), and the Estuarine Supratidal Sand subclass.

- Estuarine Intertidal Scrub-Shrub Broad Leaf Deciduous and Estuarine Intertidal Sand subclasses both made up between 1 - 2% of total habitat coverage and were represented by 47 and 37 acres, respectively. The Estuarine Intertidal Scrub-Shrub Broad Leaf Deciduous subclass was dominated by Sea Ox-eye (*Borrichia frutescens*).

- The following habitats comprised less than 1% of total habit and covered less than 12 acres (listed in decreasing order): Upland Supratidal Scrub-Shrub Needle Leaf Evergreen containing Eastern Red Cedar (*Juniperus virginiana*); Estuarine Subtidal Sand; Upland Forested Broad Leaf Evergreen dominated by Live Oak (*Quercus virginiana*), and CLC Rocky in Water Structure of the jetty at Masonboro Inlet.

4.7: Plants

The plant communities present within the Masonboro Island area are consistent with those of other barrier islands found in this part of the country. The dominant plant species for each habitat subclass are listed in the preceding section. A full species list for NCNERR is presented at Appendix 5. The Natural Heritage Program has recognized two plant species within the Masonboro plant community as significant (Table 4.6). Seabeach Amaranth (*Amaranthus pumilus*) is listed as a threatened species on both the federal and state level and is found on the foredune areas of the marine intertidal sand areas. Dune Bluecurls (*Trichostema sp*) is considered a significantly rare species on the state level, with a range limited to North Carolina and adjacent states. However, it should be noted that no Dune Bluecurls are currently found on Masonboro Island.

Submerged aquatic vegetation at Masonboro primarily consists of localized algal colonies. Seagrass beds are extremely sparse in Masonboro and Myrtle Grove Sounds. Studies have been conducted into the taxonomy, distribution and ecology of marine algae (Freeman 1989; Kapraun 1977; Kapraun and Zechman 1982; Laws et al. 1999) and introduced species (Kapraun and Searles 1990). Freeman (1989) used surveys of benthic microalgal biomass and taxonomy to indicate significance of benthic diatoms in Masonboro Sound. Distribution was found to be largely influenced by wind and temperature. Freeman also looked at consumer studies on the use of benthic microalgal biomass by the hard clam (*Mercenaria mercenaria*). Lab studies showed clams were more likely to assimilate settled microalgae than suspended microalgae. Kapraun's work (1977) is a descriptive paper of the nine species of *Polysiphonia* that occur on the N.C. coast including keys, descriptions, and illustrations from field specimens taken from Masonboro and Zeke's Islands. Growth, reproductive periods, and local spatial distributions are also noted. Kapraun and Searles (1990) present the initial documentation of the introduced benthic algae species, *Polysiphonia* (Ceramiales, Rhodophyta) in North Carolina. Specimens were collected from Masonboro Sound.

4.8: Animals

Long stretches of undisturbed beach like those found on Masonboro serve as nesting grounds for sea turtles (Webster and Gouveia 1988; Schwartz 1989; Webster and Cook 2005; Hawkes et al. 2005), shorebirds, colonial water birds, and Diamond-backed Terrapins (*Malaclemys terrapin centrata*). Numerous mudflats act as staging areas where migratory birds forage, rest and prepare for the next leg of their journey (Webster 2005). Beaches, dunes, maritime forests, and freshwater ponds offer critical foraging habitats for birds, mammals, insects, and crustaceans. The nutrient rich estuarine waters of Masonboro Sound and marsh surrounding the island are important nursery grounds for local fisheries such as Spot (*Leiostomus xanthurus*), Mullet (*Mugil cephalus*), Flounder (*Paralichthys dentalus* and *Paralichthys lethostigma*), Pompano (*Trachinotus carolinus*), Menhaden (*Brevoortia tyrannus*), and Bluefish (*Pomatomus saltatrix*). Bottlenose Dolphins (*Tursiops truncatus*) are frequently spotted in the waters surrounding the islands and in rare instances there have been West Indian Manatee (*Trichechus manatus*) sightings. A full species list for NCNERR is included as Appendix 5.

A: Invertebrates and Zooplankton

Over 250 species of macroinvertebrates have been documented on the Masonboro Island Reserve (NOAA 1984). The habitats of Masonboro support significant populations of insects, copepods, urchins, tunicates, worms, mollusks, crab and shrimp. A literature review revealed few published studies for these fauna within the Reserve. Research includes crustacean morphology (Andon 1993), description of a new copepod species (Fiers 1996) and distribution of Grass Shrimp (*Palaemontetes spp.*) (Townsend 1991). Andon (1993) used electronmicroscopy to examine the ultrastructure of the cuticle and associated tissues of the lamellar gills in the Sand Fiddler and the Grass Shrimp at all stages of the molt cycle to identify morphological and physiological adaptations of the gill structure used to cope with molting. Animals were collected from Masonboro. Fiers (1996) described a new copepod species (*Robertsonia glomerata*), found in a marsh at Masonboro. Townsend's (1991) experimental work on the depth distribution of Grass Shrimp in Masonboro tidal creeks and Maryland indicates that Grass Shrimp prefer shallow water depths.

B: Fishes

The waters around Masonboro Island are an ideal setting for detailed icthyological studies. The estuarine waters serve as important nursery grounds for species such as Spot (*Leiostomus xanthurus*), Mullet (*Mugil cephalus*), Flounder (*Paralichthys dentalus* and *Paralichthys lethostigma*), Pompano (*Trachinotus carolinus*), Menhaden (*Brevoortia tyrannus*), and Bluefish (*Pomatomus saltatrix*). The most recent survey documents 155 species of fish in the Masonboro Island vicinity (Ross and Bichy 2002). Prior work with fish can be primarily categorized as feeding behavior and trophic interactions (Cline 1992; Johnson 1994; Ogburn 1984; Pereira 1983; Perry 1982; Posey et al. 1993; Troutman 1982; Trudeau 1992) and habitat selection and utilization (Hancock 1999; Innes 1992; Necaise et al. 2005; Needham 1982; Stanley 1981; Stanley 1982; Thompson 1996). Feeding behavior was primarily studied via stomach content analysis. Cline (1992) described percent composition by number and volume of food items found in Spot and Pinfish from a Masonboro tidal creek. Johnson (1994) analyzed stomach contents of Pompano from specimens collected in the surf zone of a recently renourished area, a stretch of beach about 0.5 miles (~0.75 km) south of the renourished site, and a "natural" area about 5 miles (8 km) south of the renourished site. Percent frenquency of occurrence, volume and prey diversity were determined. Ogburn (1984) described food habits, some population biology, length-weight relationship, and size at maturity for Sheepshead (*Archosargus probatocephalus*). Pereira (1983) examined the feeding habits of three Sparids from the Masonboro Inlet jetty. Food items were expressed as percent occurrence and quantified volumetrically. Perry (1982) reported the percent frequency of occurrence of stomach contents of *Fundulus heteroclitus* and *F. majalis*. Posey et al. (1993) used caging experiments with a combination of nutrient additions, fish exclusions and inclusions, and uncaged control plots to examine ecology of benthic invertebrates (top down vs. bottom up control). Troutman (1982) wrote about food habits of *Tautoga onitis* including observations on feeding periodicity, relative and seasonal abundance, and length frequency distributions. Trudeau (1992) studied Pinfish (*Lagodon rhomboids*) diet using stomach content analysis and found that fish in silty habitats ate more of the same food items than those taken from a sandy habitat.

Several studies have focused on factors that affect nekton habitat selection and utilization. Hancock (1999) described the relationship between marsh patch size and nekton distribution. Innes (1992) presented evidence of segregation by depth for fishes in North Carolina and Chesapeake Bay. Lindquist et al. (1985) reported on the composition of fish on Masonboro Inlet jetties. Necaise et al. (2005) utilized caged studies of juvenile Summer Flounder and results suggested that basic abiotic conditions, at the levels and durations that occurred within the study, have little impact on growth, but may influence survival. Needham (1982) described fish species composition in a Masonboro tidal creek. Stanley (1981) used line transect sampling to census fish populations at Masonboro jetties. Stanley (1982) described species, relative abundance, diversity and seasonal composition of reef fishes for north and south jetties of Masonboro Inlet. Thompson (1996) used block nets to sample fish in oyster bed habitats and adjacent soft bottom habitats and compared species abundance and diversity between the two habitats.

C: Reptiles and Amphibians

The majority of the island's reptiles and amphibians are found in the upland habitats and include several species of lizards, snakes, frogs, and toads. The Diamond-back Terrapin is also occasionally found in the salt marshes. Masonboro Island is an important nesting beach for both Green (*Chelonia mydas*) and Loggerhead (*Caretta caretta*) sea turtles, which have been the focus of several research efforts. The first comprehensive picture of the relative density and distribution of Loggerhead Sea turtle nesting efforts in North Carolina was developed using aerial surveys in 1980 and 1981 (Crouse 1984). Masonboro Island was continuously monitored for nesting activities from 1985 through 1989, and again in 1990, 1991, 1994 and 1999-2002.

From 2002 until recently, the island was the only beach in N.C. not monitored. A collaborative effort between the stewardship sector of NCNERR and researchers from UNCW resumed monitoring during the 2006 nesting season. It is hoped that this effort will continue. Current and potential partners in this project include the N.C. Wildlife Resources Commission, UNCW Department of Biological Sciences, and The Pleasure Island Sea Turtle Project. The results of the turtle nest monitoring efforts have shown a slow increase in nest numbers since 1985.

The effects of nest temperature on hatchling emergence and sex determination have been studied during past monitoring (Gouveia 1988; Gouveia and Webster 1988; Neville and Webster 1988; Webster and Gouveia 1988). Studies on Masonboro Island revealed that the critical period for sex determination occurs during the latter part of the middle trimester, specifically around days 33 through 37 in a typical 60 day nest. Hentosh (1995) investigated the effects of beach nourishment that took place in 1986 and 1994 on nesting behavior. The results showed that loggerheads avoid the impact areas while nourishment activities are in progress and throughout the remainder of the nesting season. The frequency of nests and false crawls on impacted areas was found to return to normal after one year.

D: Birds

Masonboro Island provides habitat to over 250 species of birds including threatened, significantly rare, or species of special concern such as the Piping Plover (*Charadrius melodus*), Brown Pelican (*Pelecanus occidentalis*) and Black Skimmer (*Rhynchops niger*) (Table 4.6). Previous research includes population surveys and habitat utilization (Davis 1972; Everhart 1978; Kinsey 1992; Parnell et al. 1986; Smith 1988) and behavior (Warr 1991). Davis (1972) concluded man made islands at Masonboro are utilized by most species of waterway birds. Everhart (1978) compared natural and dredged material nesting site habitats of Gull-billed Terns (*Sterna nilotica*), Common Terns (*Sterna hirundo*) and Black Skimmers. Kinsey (1992) documented heavy use of intertidal habitats by birds at all seasons. The study found 55 species and nine orders and lists species by seasons, site, and habitat. Parnell et al. (1986) updated previous surveys of colonial waterbird habitats and nesting populations in North Carolina estuaries in 1983 looking at all four NERR components. Smith (1988) compared Masonboro Island and Carolina Beach ocean front beaches for bird use and found that low levels of human activity didn't seem to influence the behavior or presence/absence of birds, while high levels of human activity did influence bird activity. Warr (1991) observed foraging behavior of American Oystercatchers (*Haematopus palliates*) for a full year in several habitats. Detailed observations include foraging rate, success rate, handling time and foraging technique. Current bird management activities on Masonboro include demarcation of colonial shorebird nesting areas in conjunction with Audubon and surveys of bird breeding success with both Audubon and the N.C. Wildlife Resources Commission.

E: Mammals

The Atlantic Bottlenose Dolphin (*Tursiops truncatus*) is the primary marine mammal of the Masonboro Island component and sightings are frequent both on the ocean and sound sides of the island. Terrestrial and wetland species include the Marsh Rabbit (*Sylvilagus palustris*), Cotton Rat (*Sigmodon hispidus*), Raccoon (*Procyon lotor*), River Otter (*Lontra Canadensis*) and Mink (*Mustela vision*). Little work has been done on the mammals of Masonboro. Past studies include habitat and dietary relationships of Marsh Rabbits (Markham 1989) and comparing the abundance of terrestrial mammals at varying habitats using traps (Colwell 1983; Pyles 1973; Walls 1968). Dominant species caught were Rice Rats (*Oryzomyz palustris*), and House Mice (*Mus musculus*) (Pyles 1973; Walls 1968). Marsh Rabbits were the most abundant large mammals collected and one Eastern Cottontail Rabbit (*Sylvilagus floridanus*) was observed (Walls 1968).

Table 4.6: Species of special concern in and near Masonboro Island

State Status Codes: E = Endangered, T = Threatened, SC = Special Concern, SR = Significantly Rare, L = range limited to North Carolina and adjacent states.

Federal Status Codes: E = Endangered, T = Threatened, FSC = Federal Special Concern.

Major Group	Scientific Name	Common Name	State Status	Federal Status
Vascular Plants	*Amaranthus pumilus*	Seabeach Amaranth	T	T
Vascular Plants	*Trichostema sp*	Dune Bluecurls	SR-L	FSC
Bird	*Charadrius melodus*	Piping Plover	T	T
Bird	*Charadrius wilsonia*	Wilson's Plover	SR	-
Bird	*Egretta caerulea*	Little Blue Heron	SC	-
Bird	*Egretta thula*	Snowy Egret	SC	-
Bird	*Egretta tricolor*	Tricolored Heron	SC	-
Bird	*Pelecanus occidentalis*	Brown Pelican	SR	-
Bird	*Rynchops niger*	Black Skimmer	SC	-
Bird	*Sterna antillarum*	Least Tern	SC	-
Bird	*Sterna hirundo*	Common Tern	SC	-
Bird	*Haematopus palliatus*	American Oyster Catcher	SR	-
Bird	*Catoptrophorus semipalmatus*	Willet	SR	-
Reptile	*Caretta caretta*	Loggerhead	T	T
Reptile	*Chelonia mydas*	Green Turtle	T	T
Reptile	*Crotalus adamanteus*	Carolina Diamondback Terrapin	SC	-
Fish	*Evorthodus lyricus*	Lyre Goby	SR	-
Mammal	*Trichechus manatus*	West Indian Manatee	E	E

Data from the North Carolina Natural Heritage Program

4.9: Invasive Species

Masonboro Island has few invasive species. Beach Vitex (Vitex rotundifolia) has been found and removed from one location. In the future, this species will likely become more problematic. It has become established on several islands to the south and has demonstrated an ability to rapidly invade native communities. Common Reed (Phragmites australis) is found on some of the dredge spoil islands lining the Intracoastal Waterway on the backside of Masonboro Island. Red Foxes (Vulpes vulpes) (Figure 4.10) are not native to North Carolina, but were introduced in colonial times for the purpose of sport hunting. Red

Figure 4.10: Red Fox.

Foxes have had a significant negative impact on colonial nesting bird and sea turtle nests on Masonboro Island and surrounding areas. Research reports a large and continuous population on nonnative red foxes throughout the eastern U.S., with increasing populations which have negative impacts on native species (Kamler and Ballard 2002). Nutria (*Myocastor coypus*) is also a potential threat likely to invade the Reserve in the near future. These rodents have been sighted in coastal habitats near Masonboro.

4.10: Stressors

The Masonboro Island Reserve component is exposed to a variety of stressors, both natural and anthropogenic (man-made). Natural stressors include hurricanes, sea level rise, and drought. Anthropogenic stressors include altered land use, pollution, nutrient loading, and habitat disruption. Some of the key stressors are discussed in detail below.

A: Altered Land Use

The type of land cover present is a critical issue because how the land is used and the type of cover on it has large impacts on its ability to sequester nutrients and pollution rather than convey them to surface waters. Natural land covers with vegetative cover such as forest and marsh have large buffering capacities. They tend to trap nutrients and sediment prior to them entering surface waters. Developed land tends to have very little capacity to absorb nutrients and pollution. This is because developed land has increased impervious surfaces such as roofs, roads, and parking lots. These surfaces do not let water infiltrate the ground and high percentages of impervious surfaces have been correlated with degraded water and sediment quality (Holland et al. 2004; Mallin et al. 2000b). Consequently, stormwater runs off these surfaces picking up whatever contaminants and nutrients are on them and rapidly moves these materials to surface waters (Mallin et al. 2000b; Mallin et al. 2001).

New Hanover County’s estimated population growth from 1990-2000 was 36.6 % (North Carolina Department of Environment and Natural Resources 2005). The growth trend for this area is expected to continue with a forecasted population increase of 31.4 % for 2000-2020 (North Carolina Department of Environment and Natural Resources 2005). To assess the amount of change within the Masonboro Island watershed, land cover types were evaluated for the two most recent years that data were available, 1991 and 1997. Land cover information was obtained for coastal North Carolina from NOAA's Coastal Change Analysis Program. Figure 4.11 shows the land cover maps for 1991 and 1997 for the Masonboro Island watershed (United States Geological Survey - Hydrologic Cataloging Unit 03030001). It should be noted that the United States Geological Survey includes Masonboro Island in the New River watershed. This is in contrast to the State of North Carolina designation which places Masonboro Island in the Cape Fear watershed (as presented in the Hydrology and Water Quality section). The NERRS habitat mapping protocol calls for United States Geological Survey delineations, thus they were used in this analysis. See Appendix 4 for detailed methodology. The State of North Carolina includes the New River watershed as a sub-basin of the White Oak River Basin (See Chapter 3, Section 3.5, Figure 3.2).

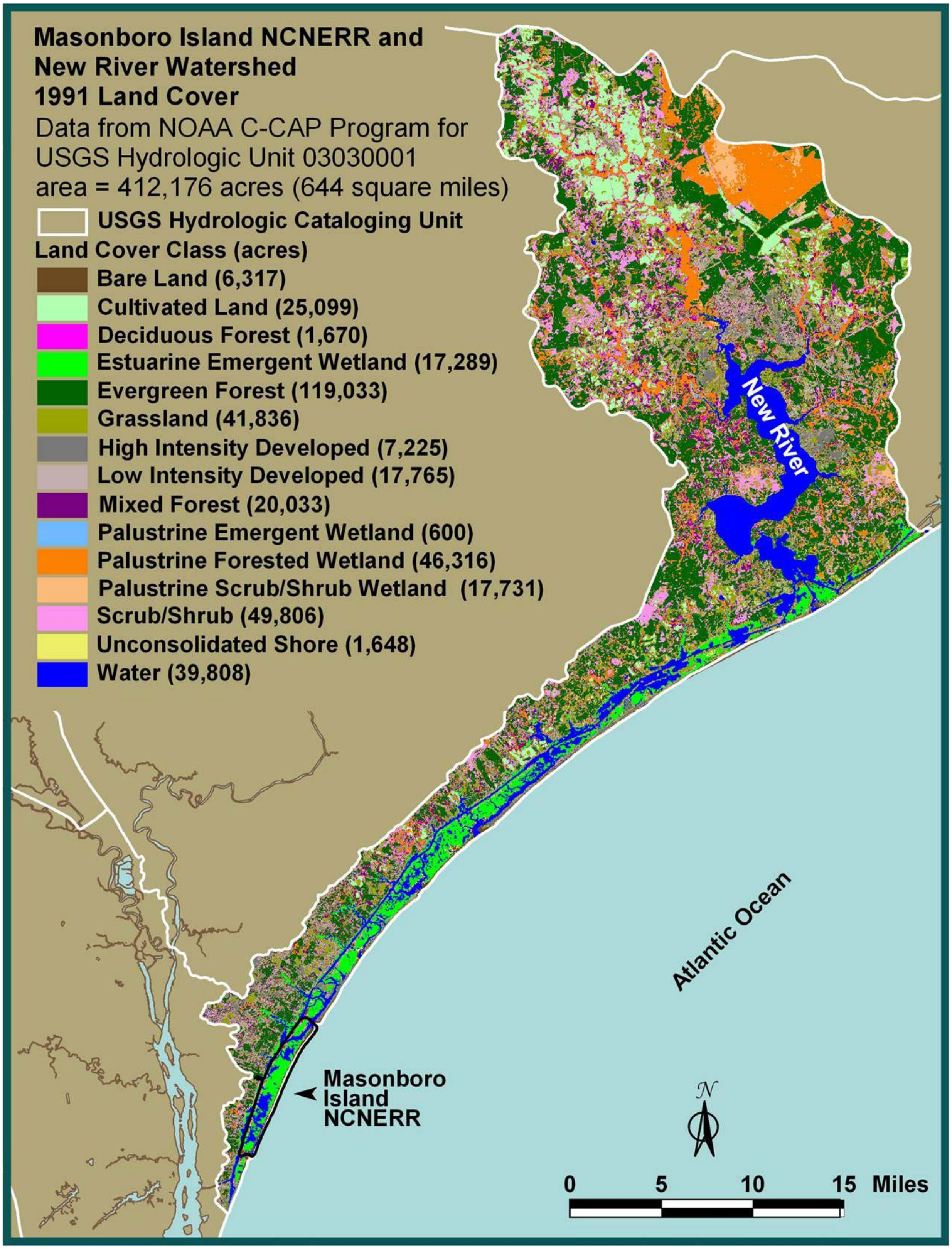


Figure 4.11a: Land use classification from 1991 in the Masonboro Island watershed.

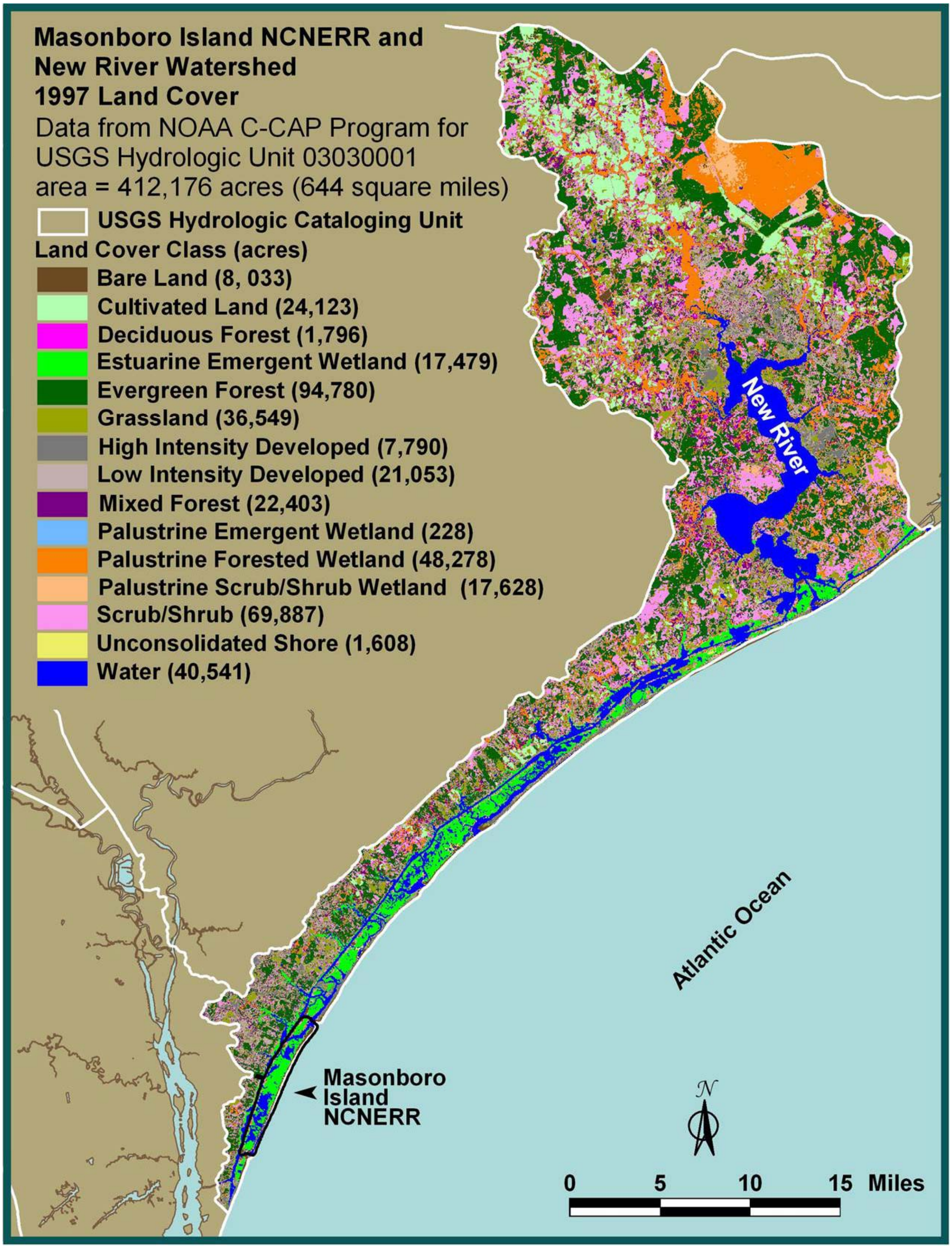


Figure 4.11b: Land use classification from 1997 in the Masonboro Island watershed.

The major land cover types were Evergreen Forest (29% in 1991, 23% in 1997) and Scrub/Shrub (12% in 1991, 17% in 1997), dispersed throughout the watershed. Palustrine Forested Wetland was also prevalent (11% in 1991, 12% in 1997) with a large stand found in Hofmann State Forest in the northeast region. Low and High Density Developed (6% in 1991, 7% in 1997) were concentrated around Jacksonville at the head of Morgan Bay, and suburban Wilmington, west of the Masonboro Island component. For clarity the changes that occurred between 1991 and 1997 have been grouped into three categories: 1) decreased vegetation cover (of any type), 2) increased vegetation cover (of any type), and 3) a change from one type of non-vegetated cover to another (neither an increase of decrease of vegetation). The decrease in vegetation cover category includes all areas where the Land Cover changed between 1991 and 1997 to a class that characterizes conditions with generally less plant cover or biomass. Examples of this category are a transition from Forested to Grassland or Scrub-shrub to Low Density Development. The increase in vegetation cover category was assigned to all areas where the Land Cover changed to a class that represents generally greater plant cover or biomass. Examples of this category are succession of grassland to Scrub-Shrub and Scrub-Shrub to Forested. The change in non-vegetated cover category designates all areas that had different non-vegetated land cover classes in 1991 and 1997. Examples included water to unconsolidated shore, unconsolidated shore to bare land and bare land to low-density developed. Figure 4.12 and Table 4.7 show the changes between 1991 and 1997 associated with these three groups.

Table 4.7: Change in land cover from 1991 to 1997 in the Masonboro Island watershed

Category	Acres	% of total
Total mapped area	412,176	n/a
Water area	39,705	9.6
Total land area	372,471	90.4
Decrease in vegetative cover	32,449	8.7
Increase in vegetative cover	18,644	5.0
Change from one unvegetative cover to another	602	0.16
Unchanged land cover	320,776	86.1
Net decrease of vegetation = 3.7%		
Percent of land area with changed cover types = 13.9%		

Changes that occurred between 1991 and 1997 affected 14% of the watershed (see Figure 4.12). The increase in vegetated conditions (5%) was due primarily to succession: Grassland to Scrub/Shrub and Palustrine Scrub/Shrub Wetland to Palustrine Forested Wetland throughout the northwestern region. Decrease in Vegetative Cover (9%) was dominated by conversion of Evergreen Forest to Scrub/Shrub and Grassland clustered west of the Intracoastal Waterway, 20 miles either side of the mouth of the New River. Between 1991 and 1997, the loss of vegetated conditions to Low and High Density Developed was 1%, primarily from Evergreen Forest and Grassland, spread throughout the watershed.

In the ten-year period from 1990 to 2000, the population of Wilmington grew by 62.7%, while the population of New Hanover County grew by 33.9% (Development Services Department, 2005).

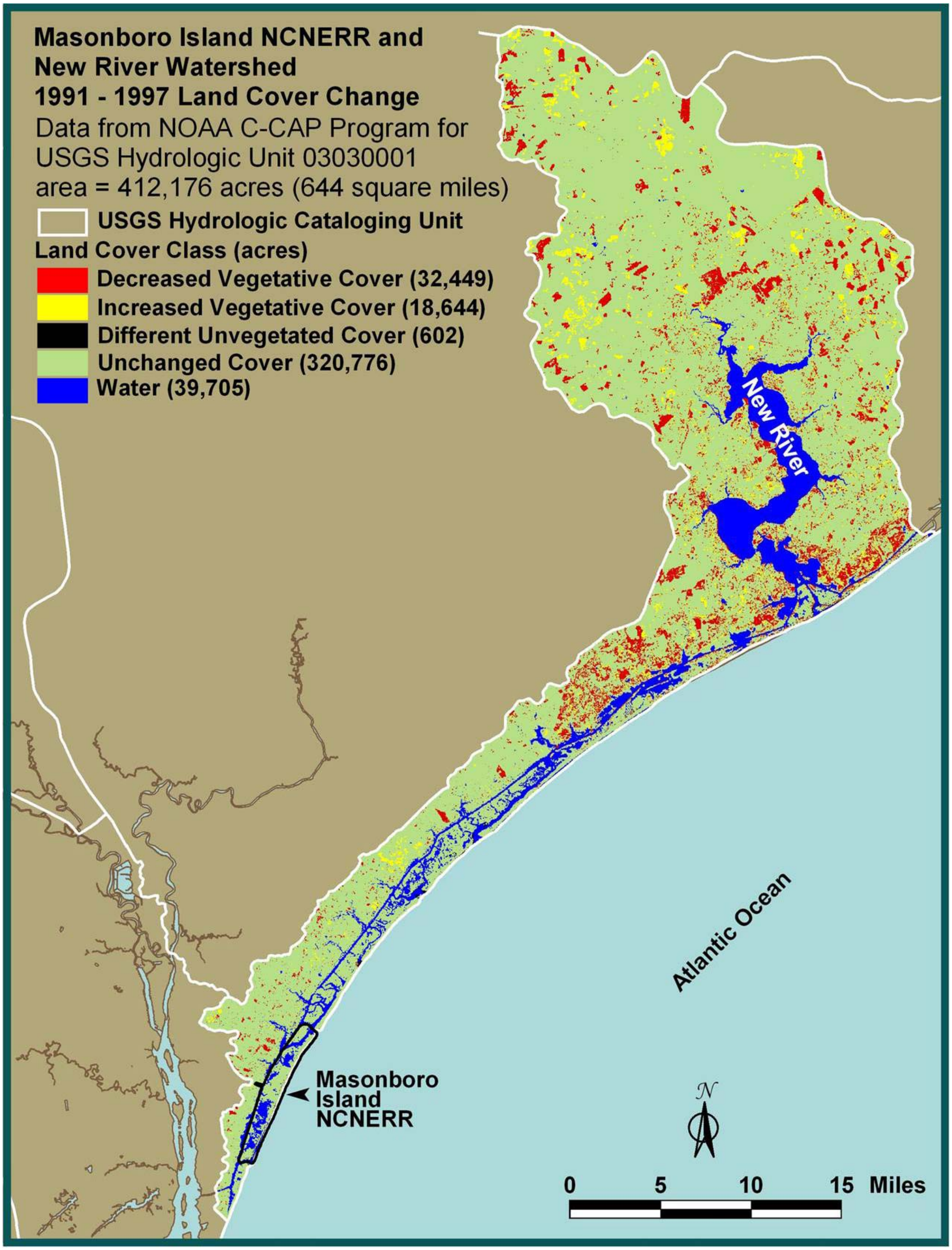


Figure 4.12: Changed land cover between 1991 and 1997 in the Masonboro Island watershed.

While part of the increase in Wilmington is attributable to annexation, these figures indicate explosive immigration to the area. In the five years from 2000 to 2005, population growth for Wilmington was 4.7% and 9.7% for New Hanover County. Projections for the area indicate continued growth, with Wilmington moving from a 2005 population of 94,531 to 110,220 in 2020. New Hanover County is expected to grow from 176,575 to 230,386 during the same period. Thus, it is highly anticipated that the loss of vegetative cover noted from 1991-1997 has continued in the years since 1997. This will be investigated further with the anticipated release of new Land Cover/Change data since covering the time period 1997 to 2005.

Bounded by the Cape Fear River to the west and the Intracoastal Waterway to the east, Wilmington must accommodate this increase in population in a fairly constricted setting. Accomplishing this task will increase pressure on the existing municipal infrastructure, some components of which (such as the sanitary sewer) are currently at or exceeding capacity. The city of Wilmington has experienced a series of sewer system failures since 2005 that have dumped millions of gallons of sewage into both the Cape Fear River and the tidal creeks feeding Masonboro Sound (Gannon 2006a and 2006b) (See section 4.5). Accommodating this growth will also increase the conversion of vegetative cover to impervious surface in both the Cape Fear and New River watersheds. These changes could negatively impact adjacent water quality by enhancing storm water runoff (Mallin et al. 2000b, Mallin et al. 2001). It will be critical to continue the water quality monitoring currently in place to document the changes as the Wilmington area and New Hanover County grow.

B: Visitor Use

As the only undeveloped barrier island in the Wilmington, N.C. area, Masonboro Island receives heavy visitor use, especially during the summer months. Holidays are marked by intense visitation, especially at the northern and southern termini of the island. Heavy visitor use is associated with some degradation of the resource, especially in the form of littering. Several citizen groups and dedicated individuals have worked to police the island following holiday events. Recent collaboration with the North Carolina Coastal Land Trust has worked to coordinate cleanup efforts and increase citizen awareness of the consequences of littering on the island. Other impacts, such as camp fire rings, are mitigated by natural processes of sand drift and ocean overwash. The impacts of recreational use on Masonboro Island have been investigated by former NCNERR staff and UNCW researchers for over a decade (Buerger et al. Buerger et al. 1994; Buerger et al. 1995; Buerger et al. 2000; Buerger et al. 2003).

C: Sea Level Rise, Shoreline Change, and Hurricane Impacts

Sea level rise is a well documented phenomenon (Kaufman and Pilkey 1993). As sea level rises, barrier islands retreat landward (Leatherman 1988). Research in the late 1970s found that Masonboro Island had migrated landward as much as 200 feet in the previous 30 years (Hosier and Cleary 1977). More recent estimates put overall landward migration of the island at approximately 12 feet (3.6 m) per year. The southern portion of the island suffers from sediment deficiency and while this condition enhances migration of barrier islands, if the rate of sea-level rise is too great, then the barrier island may be drowned and left as a submerged sand shoal on the continental shelf (Morton and Miller 2005).

An additional consideration is the impact of sea level rise on the flora of the island. Migration requires plants to reestablish themselves in areas affected by overwash. This overwash may bury marshes on the back side of barrier islands. Barriers that are forced to migrate too rapidly may outpace the ability of vegetative communities to reestablish themselves (Schafale and Weakley 1990). Lack of stabilizing vegetative communities can enhance erosion and lead to loss of the island over time. As Masonboro Island continuous to erode and migrate shoreward due to sea level rise, storms and human alterations, there will be a plethora of opportunities to study shoreline change on this barrier island. Alterations from hurricanes as well as shoreline recovery have been studied previously (Moundalexis et al. 1997; Moundalexis et al. 1998; Sault et al. 1999). The height of the Dunes on Masonboro was reduced dramatically following the impacts of Hurricane Bertha and Fran in 1996.

4.11: Research Activities

The information in this section is in a rapid state of flux. Research projects are constantly being initiated, executed and completed. As a result, this section will rapidly become dated. Despite this complication, it is still beneficial to describe the current body of research in this manner. The past projects represent a large foundation which future projects can utilize as planning guides. The projects currently being worked on are designed to address current high priority coastal management issues. Thus, in addition to the actual research results, these projects will provide future interested parties with awareness into what the high priority issues were for the Reserve at this time. The needed research represents current knowledge gaps that need to be addressed. While future projects may address some of these, the underlying issues such as eutrophication and sea level rise will still be valid.

A: Research Facilities

There are no research facilities on Masonboro Island. The NCNERR office is located directly across Masonboro Sound from Masonboro Island at the University of North Carolina at Wilmington's Center for Marine Science. This arrangement is codified by a long-standing memorandum of agreement between the North Carolina Department of Coastal Management and the University of North Carolina Wilmington and an annual contract for services. The Center for Marine Science office covers 1,450 square feet, and provides offices for research staff as well as other staff, a common area/workspace, a storage area/mud room, and a large laboratory. The Center for Marine Science also affords NCNERR access to conference rooms, a machine shop, and boat dock access to Masonboro Sound. NCNERR owns three boats designated for research and stewardship that are housed at the Wilmington office.

B: Historical Research Activities

There has been a great deal of work conducted on Masonboro Island and the surrounding waters. Many of these projects have been highlighted in the previous sections of this chapter. Others are presented in Appendix 6, the bibliography of work conducted within NCNERR. The large body of work is due in part to the presence of a major research university (UNCW) in such proximity to the Reserve. Another is the uniqueness of an undeveloped barrier island in the southern North Carolina region. Masonboro is ideal for use as a control site for adjacent impacted areas. Some of the major findings from the prior research are presented below. Masonboro Island is an extremely dynamic landform rapidly moving shoreward. The extensive marshes on the soundside of Masonboro Island are important nursery areas for estuarine nekton (Ross and Birchy 2002). Masonboro Island was dramatically altered due to hurricanes, specifically by the cumulative effect of two storms in 1996 (Buerger et al. 2003). Visitor use has caused impacts to the environmental resources of Masonboro Island (Buerger et al. 1994; Buerger et al. 1995; Buerger et al. 2000; Buerger et al. 2003). Researchers from NOAA's Center for Coastal Environmental Health and Biomolecular Research in Charleston, SC recently completed a project at Masonboro Island examining the sediments in the Reserve using an EPA-Environmental Monitoring and Assessment Program style sampling design. The results of this project showed that the overall condition of the sediments within the Reserve was good and contaminant loads were relatively low (Cooksey and Hyland 2007).

C: Current Research Activities

There are currently several research and monitoring projects being conducted on Masonboro Island and its adjacent Sounds. This work is being done by NCNERR staff and outside researchers from universities, government agencies, and non-government agencies. A representative sample of these studies is discussed in greater detail below.

All the water quality monitoring programs mentioned in section 4.5 are still being conducted. The SWMP monitoring conducted by NCNERR staff was recently enhanced with satellite uplinks that allow NCNERR SWMP data to be incorporated into the Integrated Ocean Observing System. The integrated ocean observing system is a network of monitoring platforms across the nation that provide weather and water quality data in near real time. This data is available via the internet to anyone with a computer connection. NCNERR data is available from NOAA's Centralized Data Management Office at http://cdmo.baruch.sc.edu/. Efforts continue to add telemetry capability to NCNERR's remaining SWMP stations.

The sea turtle nesting monitoring program that was restarted in 2006 is also ongoing. Data from 2007 indicate total number of nest declined from 2006 levels. Red Foxes (*Vulpes vulpes*) were also found to be an extremely significant predator on sea turtle eggs. This research will allow the continued success of Loggerhead nesting to be documented for Masonboro Island. This data is critical as it can be used to compare against similar barrier islands with development. The difference between the nesting successes on Masonboro to that from developed neighbors will allow researchers to determine the impact of ocean development on sea turtle nesting success.

A visitor use survey was conducted in the summer of 2007. This project was conducted by both NCNERR staff and researchers from UNCW. Data analysis is currently being conducted. This project will allow site managers for Masonboro to better understand the public use that Masonboro receives. This will allow more efficient management of the island to maximize public benefit without negatively impacting the natural community.

Work is being conducted on Masonboro to study the groundwater: lens height; recharge and discharge rates; and geochemical makeup. This work is being conducted by researchers from UNCW and will provide valuable information regarding the water cycle on Masonboro Island.

Other studies include an investigation by a UNCW researcher into the common mudsnail (*Ilyassoma obsoleta*). The goals of this project are to examine the neural mechanisms of metamorphorsis within this species relative to environmental conditions. A study by another UNCW researcher is examining the use of Masonboro Island by several sparrow species. Goals of this project are to determine habitat use, diet and population size and age. NCNERR staff is working on a project examining the changes in water quality around several oyster reef restoration projects at Masonboro Island. The goal of this project is to document water quality changes as the oyster reefs transform from bare shell to living reef. Monthly sampling includes physical-chemical water quality parameters as well as fecal coliform and Chlorophyll *a* concentrations.

4.12: Future Research Needs

Despite the large body of work that has been completed at Masonboro Island, there still is much we do not know. Below are some high priority research needs for Masonboro Island.

A study measuring the impact of red fox predation on bird populations needs to be conducted. Red foxes have been shown in other areas to dramatically impact the nesting success of birds. Given the high diversity of bird species on Masonboro coupled with the threatened status of some of them, this usefulness of this study is clear. The results from this study would provide information that would help manage Masonboro as well as many other coastal areas. The North Carolina Wildlife Resources Commission and the Bald Head Island Conservancy would be ideal partners to assist with this project.

A hydrological study of Masonboro sound needs to be conducted so the sources and fates of nutrients and pollutants entering the tidal creeks on the mainland side of Masonboro Sound could be predicted. This study will help managers better manage shellfish beds in the region. It would also help clear up the relationship of Masonboro and Myrtle Grove Sound relative to the Cape Fear and New Rivers. Ideal partners to help accomplish this study would include the United States Geological Survey, and UNCW. The Geological Survey has a long history of conducting hydrological investigations and has the required equipment and expertise to do so at Masonboro. UNCW also has several local experts in the physical circulation of water on staff.

The sea turtle nesting monitoring program currently being conducted on Masonboro could benefit greatly from a research project aimed at determining the nesting success of sea turtles relative to the frequency of beach renourishment. Beach renourishment is being conducted at almost all of North Carolina's beaches. The impact of this on sea turtle nesting success is not well understood. Masonboro would be an ideal place to conduct this test as areas of the beach receive nourishment and other areas do not. Ideal partners to assist with this project would include the N.C. Wildlife Resources Commission, UNCW Department of Biological Sciences, and The Pleasure Island Sea Turtle Project.

A study into the potential impacts of sea level rise also needs to be conducted. Marsh accretion rates for various areas of Masonboro need to be determined. This would allow us to predict which areas of the island were most in danger of eroding away and would allow stewardship activities to be targeted in areas with the greatest chance of success. This dataset would also assist the nationwide effort to understand the impacts sea level rise will have on the coastal areas of the United States.

A study needs to be conducted into why seagrass does not currently inhabit the Masonboro region. Seagrass occurs both north and south of the Masonboro region. Selected areas could be reseeded with appropriate seagrass species and monitored for success. Environmental conditions (such as light penetration, turbidity, nutrient concentrations, sediment surface stability, etc.) at the restoration locations would be monitored in the hopes that the critical parameter limiting sea grass growth at Masonboro could be determined.

Chapter 5:   Zeke's Island Component

5.1:   Environmental Setting

The Zeke's Island component of the NCNERR is located in portions of both Brunswick and New Hanover counties, in south-eastern North Carolina just south of Kure Beach (Figure 5.1). The nearest population center is Wilmington, N.C. located 22 miles (35 km) to the north. Southport, N.C. is located across the Cape Fear River 10 miles (16 km) to the south-southwest. Zeke's Island is bounded to the north by Federal Point (encompasses Fort Fisher State Park and the North Carolina Aquarium at Fort Fisher), to the east by the Atlantic Ocean, the Cape Fear River to the west, and the Smith Island Complex to the south. Zeke's Island is located in the Cape Fear River basin and on a broader scale in the Carolinian biogeographic province (Figure 5.1).

Zeke's Island was one of the three original NERR components dedicated by NOAA and DCM in 1985 (Masonboro was added in 1991) and includes 1,165 acres (4.7 km^2). Zeke's Island is accessible by both foot traffic and boat. A boat ramp is present at the Northern end of the Reserve providing boat access to the basin area (Figure 5.1). Walking trails into the Reserve are provided through a partnership with the North Carolina Aquarium at Fort Fisher.

5.2:   Historical Uses

A: Native American Usage

Prior to English settlement, the area around Zeke's Island was likely used as a hunting ground by Native American Indians. The Eastern Seaboard of the U.S. including North Carolina was inhabited by Algonkian speaking tribes. Midden evidence clearly demonstrates that coastal shellfish were an important food source for these peoples (Claassen 1986). Evidence for a native presence in the region is also provided by the accounts of early settlers (see below).

B: Colonial Uses

William Hilton, a New England explorer, sailed and explored the Cape Fear region during 1663-1666. His report enticed colonists from Massachusetts Bay Colony to try to settle in the area during the winter of 1663-1664. This settlement attempt failed as well as other attempts from 1664-1667. These settlement efforts did not succeed due to inadequate external support, internal dissention and hostile relations with Native Americans. A permanent European settlement known as Brunswick Town was founded in 1726 by Maurice Moore upstream of the Reserve sight on the western bank of the Cape Fear River (Watson, 1992). Brunswick Town became a vital port city specializing in naval-stores and rice produced by the nearby plantations which had been built in the region (Atkinson et al. 1998).

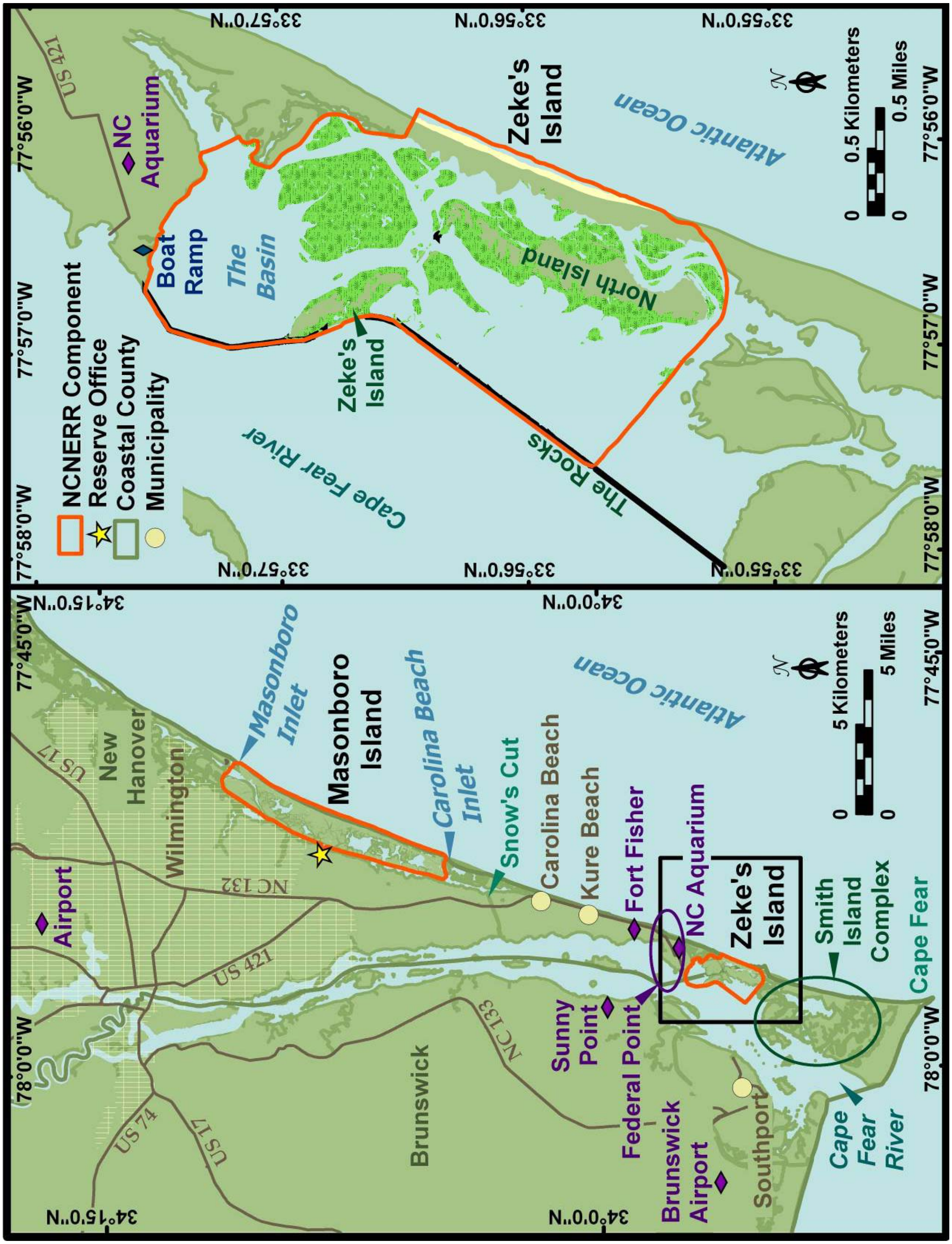


Figure 5.1: Zeke's Island location. The top panel shows a close up of Zeke's Island.

The importance of Brunswick Town waned after the rapid development and incorporation of Wilmington (Watson 1992). Wilmington grew into the primary port for the region largely due to the improvement in transportation infrastructure (ferries and roads) that occurred in the region during the 1770s (Watson 1992). In 1776 the last few people living in Brunswick Town were forced out when British troops burned the city during the Revolution and Brunswick Town lost representation in the General Assembly (Watson 1992). Today foundations of many of the town's buildings can be seen along with the exterior walls of the town's church.

C: Civil War Uses

When the civil war broke out, the port of Wilmington became critical to the success of the Confederacy. In an effort to keep the blockaders at bay and protect the runners when entering and leaving Wilmington, the Confederate Army constructed numerous earthern fortifications at the mouth of the Cape Fear River (Campbell 2005). During 1861-1862 the most prominent of these forts, Fort Fisher, was fortified and used as the main defense for Wilmington. Fort Fisher's guns were able to protect confederate blockade runners until late 1864 (Moorefield 1978). In January 1865, Fort Fisher fell to the Union army during a combined land and sea attack (Atkinson et al. 1998). Since 1865 the ocean has eroded much of the original fort. Only remnants of the western most edge of the original fort survive today.

D: Post Civil War Uses

Between 1875 and 1881, the U.S. Army Corps of Engineers constructed "The Rocks" – a massive breakwater running from Federal Point to Zeke's Island, and from Zeke's Island southward through the Smith Island Complex (Figure 5.1). Designed to reduce shoaling in the Cape Fear River, the Rocks drastically reduced the flow of water through New Inlet, which cut through the area now encompassed by the Reserve, and caused extensive changes in the landforms of the area. New Inlet migrated southward while Zeke's Island grew significantly in length. During the six years after the construction of the dam, New Inlet migrated from 580 meters per year to as much as 0.6 miles (1 km) per year before eventually closing (Cleary and Marden 2001). During the late 1800s Zeke's Island was home to a turpentine factory and a center for gill net fishing before these were destroyed during a hurricane in 1899 (Atkinson et al. 1998).

The Fort Fisher area was utilized for military purposes again during World War II. Equipment and usage included: a radar tower, artillery targets, ammunition bunkers, and an airstrip. After World War II and to present day, this area serves as a buffer zone to the Sunny Point Ammunition Loading Terminal located on the western side of the Cape Fear River (Figure 5.1) (Moorefield 1978). Sunny Point is the largest ammunition port in the nation, and the Army's primary east coast deep-water port (Figure 5.1). This use has restricted development in the area, and allowed the natural habitats to be preserved. The only permanent structures south of Kure Beach are a State Park centered on the remains of Fort Fisher, the southern facility of the North Carolina Aquariums, and a ferry terminal for the North Carolina Department of Transportation. This natural area provides public beach access and is used heavily as a recreational destination for swimming, kayaking, and fishing.

5.3:   Climate

The nearest reliable weather station to the Zeke's Island area is located at the Brunswick County airport in Southport, N.C. (Figure 5.1). This weather station is maintained as part of the National Weather Service network of reporting stations. Annual mean temperature for the region from 1892 to 2004 was 62.9 °F (17.2 °C). The coolest temperatures occur in January, with average daily temperature of 45.4 °F (7.4 °C), and the warmest average daily temperature, 79.8 °F (26.5 °C) occur in July (Figure 5.2). Average annual rainfall for Southport is 61 in (155 cm). Historically, September has the highest rainfall amount with a monthly average of 9 in (23 cm), and April has the lowest rainfall with an average of 3 in (8 cm).

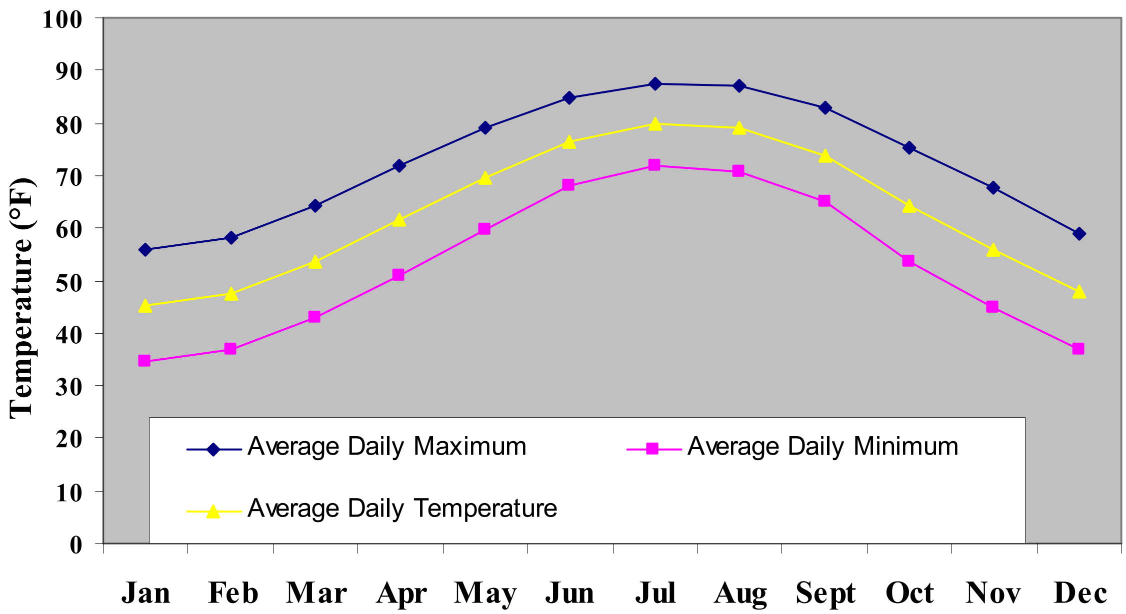


Figure 5.2: Average, minimum and maximum daily temperatures 1892 – 2004 by month for Southport, NC. Figure from NOAA-National Climatic Data Center.

The highest yearly rainfall recorded (70.47 in (27.7 cm) occurred in 1946. The driest year on record occurred in 1931 with an annual rainfall of only 27.99 in (11.0 cm) (Table 5.1). Snow and sleet are rare for this area due to the warming effect of the ocean in winter, but do occasionally occur.

Table 5.2 lists the named storms that have passed within 65 nm of Zeke's Island over the past 50 years. Notable storms include Bertha and Fran in 1996 which caused extensive damage to the Wilmington area. In 1999 Hurricane Floyd passed directly over Zeke's Island before moving north. The rainfall associated with Floyd led to extensive flood damage to southeastern North Carolina. More recently, hurricane Ophelia passed Zeke's Island just offshore in September of 2005 bringing large amounts of beach front erosion and large amounts of rainfall. The area has also experienced several Nor-Easter's during this time period, however these storms are not named and tracked as hurricanes are.

Table 5.1: Top ten highest and lowest annual precipitation amounts for Southport, N.C. recorded 1892 – 2004

Top 10 highest precipitation amounts 1892 – 2004		
Rank	Precipitation (in)	Date
1	70.47	1946
2	69.55	1947
3	69.00	1996
4	68.11	1987
5	67.21	1936
6	67.10	1922, 79
7	66.38	1969
8	66.29	1945
9	64.90	1971
10	64.82	1984
Top 10 lowest precipitation amounts 1892 – 2004		
Rank	Precipitation (in)	Date
1	27.99	1931
2	31.44	1923
3	34.79	1941
4	34.99	1940
5	35.72	1894
6	35.89	1903
7	36.56	1911
8	36.82	1926
9	36.91	1954
10	37.30	1902
Data from NOAA – National Climatic Data Center		

5.4: Geological Processes

The Zeke's Island component contains surface sediments representative of the coastal plain. These sediments are varying combinations of sand, silt and clay, from terrestrial and marine sources. Some of these deposits are considered Recent (less than ~11,550 years old) and some are of Pleistocene (~1.8 million to ~11,550 years before present) origin. The Pleistocene deposits are thin blankets of marine and estuarine sands and clays occurring in a series of terraces and scarps related to previous shoreline locations. These deposits overlay layers of Cretaceous (~140 to ~70 million years before present) and Tertiary (~70 to ~1.8 million years before present) terrigenous and carbonate deposits (Atkinson et al. 1998, Moorefield 1978).

The Cape Fear region is representative of coastal cape formations along North and South Carolina. Shoals often extend seaward from these cape areas. Frying Pan Shoals extends seaward from the Cape Fear estuary area outward to approximately 31 miles (50 km). Barrier island formations generally extend north and southwest off these cape regions. The accepted theory is that the capes have maintained their basic positions and morphologies throughout the Pleistocene and Holocene (~11,550 years ago to present) by migrating landward or seaward in response to sea level changes (Moorefield 1978).

Ocean inlets have historically formed, migrated, and closed within the barrier-spit area of Zeke's Island. The last oceanic inlet in this area, the New Inlet, closed in March 1999 (Cleary and Marden 2001). Currently water exchange is dependent on the adjacent Cape Fear River (see below). Coastal processes continue to change and rework the beach environments that produce the barrier island and estuarine features found around Zeke's Island.

Table 5.2: Tropical storms passing within 65nm of Zeke's Island since 1956

Storm	Date	Name	Wind (kts)	Minimum Pressure (mb)	Classification
1	Sept 1956	Flossy	35		Extratropical
2	June 1957	Not Named	35		Tropical storm
3	Sept 1958	Helene	110	934	Category 3 hurricane
4	July 1960	Brenda	45		Tropical storm
5	Sept 1960	Donna	90	966	Category 2 hurricane
6	Sept 1961	Not Named	30		Tropical depression
7	Aug 1962	Alma	45	1002	Tropical storm
8	Oct 1963	Ginny	85		Category 2 hurricane
9	June 1964	Not Named	35		Tropical storm
10	Sept 1964	Dora	45		Tropical storm
11	June 1966	Alma	40	997	Tropical storm
12	June 1968	Abby	25		Tropical depression
13	Oct 1968	Gladys	75		Category 1 hurricane
14	Aug 1970	Not Named	30	1013	Tropical depression
15	Aug 1971	Doria	50	998	Tropical storm
16	Oct 1971	Ginger	60	991	Tropical storm
17	June 1972	Agnes	30	990	Tropical depression
18	June 1975	Amy	25	1012	Tropical depression
19	Oct 1975	Hallie	35	1003	Tropical storm
20	Sept 1977	Clara	20	1014	Tropical depression
21	Aug 1981	Dennis	45	1001	Tropical storm
22	June 1982	Subtropical 1	60	992	Subtropical storm
23	Sept 1984	Diana	100	960	Category 3 hurricane
24	Oct 1985	Isabel	25	1012	Tropical depression
25	Nov 1985	Kate	45	996	Tropical storm
26	Aug 1986	Charley	55	995	Tropical storm
27	Aug 1987	Arlene	10	1016	Tropical low
28	June 1995	Allison	35	995	Extratropical
29	June 1996	Arthur	35	1006	Tropical storm
30	July 1996	Bertha	85	975	Category 2 hurricane
31	Sept 1996	Fran	100	952	Category 3 hurricane
32	Oct 1996	Josephine	45	988	Extratropical
33	Aug 1998	Bonnie	100	965	Category 3 hurricane
34	Sept 1998	Earl	50	995	Extratropical
35	Sept 1999	Floyd	90	950	Category 2 hurricane
36	Oct 1999	Irene	70	978	Category 1 hurricane
37	June 2001	Allison	25	1006	Subtropical depression
38	Oct 2002	Kyle	35	1011	Tropical storm
39	Aug 2004	Alex	70	983	Category 1 hurricane
40	Aug 2004	Bonnie	25	1008	Tropical depression
41	Aug 2004	Charley	65	988	Category1 hurricane
42	Sept 2005	Ophelia	80	976	Category 1 hurricane
Data from the NOAA – Coastal Services Center					

A study into the sediment characteristics was conducted by Reserve staff in the mid 1990s. The sediments were analyzed for carbon and nitrogen content. These parameters are a good indicator of the amount of organic matter present. Organic matter tends to be very light and usually only settles in deeper areas with low energy conditions. Figure 5.3 shows the results of the sediment mapping efforts. The highest organic matter in the Reserve was located in the northwest portion of the basin (Figure 5.3). It should be noted that this work was conducted when an inlet opening to the ocean was present. Recently, as part of a nutrient flux study conducted in the Reserve, sediment samples were taken from the area in the basin that had the highest values and an adjacent area that originally showed very low values. The recent samples showed the same pattern for these regions. These depositional areas could also be a hotspot for contaminants. Many contaminants adhere to sediment particles and get deposited as the particles settle. Researchers from NOAA's Center for Coastal Environmental Health and Biomolecular Research in Charleston, SC recently completed a project at Zeke's Island examining the sediments in the Reserve using an EPA-Environmental Monitoring and Assessment Program style sampling design. The results of this project showed that the overall condition of the sediments within the Reserve was good and contaminant loads were relatively low (Cooksey and Hyland 2007). Unfortunately, the randomly chosen sample sites did not coincide with the area of high nitrogen. This gap in spatial coverage needs to be addressed with additional contaminant studies.

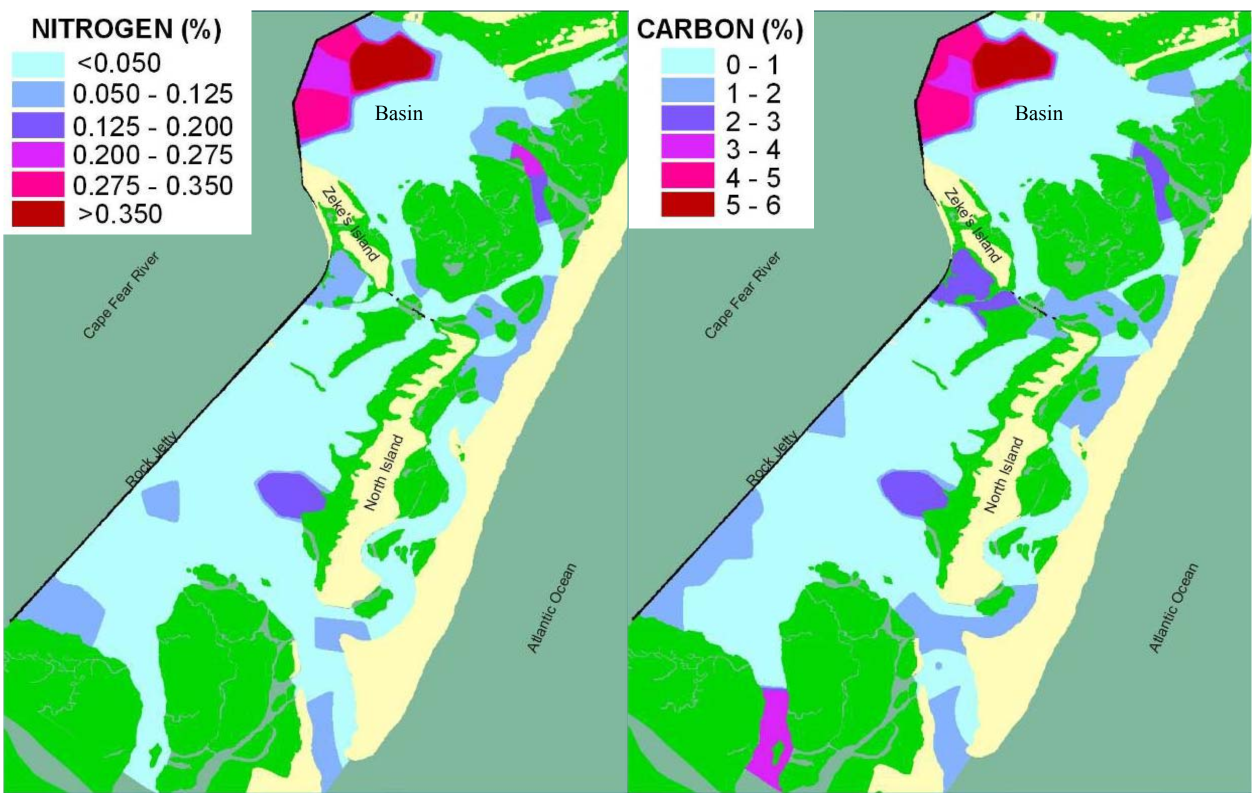


Figure 5.3: Subtidal sediment percent nitrogen (left frame) and carbon (right frame). Areas with the highest nitrogen and carbon are shown in red. The highest values are found in the northwest corner of the basin.

5.5: Hydrology and Water Quality

There are two bodies of water that contribute to water quality at Zeke's Island. Along the beach front, the Atlantic Ocean is the primary influence for water quality. Within the tidal creeks and Basin of Zeke's Island, the primary influence is the lower Cape Fear River Estuary (Figure 5.4). During periods when there is an open inlet at this Reserve component the two water sources mix and water quality is influenced by both. However, when there is not an active inlet, like currently exists today, these two water sources are separated and act independently on their respective spheres of influence.

A: Ocean-side

a: Hydrology

The tide range on the Ocean side of Zeke's Island is about 3.5 ft (1 m) during normal diurnal cycles and can reach almost 5 ft (1.5 m) during spring high tides (Ross and Bichy 2002). The offshore environment is influenced by warm core eddies that spin off the Gulf Stream and discharged water from the Cape Fear River. The near shore currents move sediment on and off the beach. This process is enhanced during coastal storms.

b: Water Quality

The beach front at Zeke's Island is a popular location for recreational activities. Consequently, the quality of the ocean water is extremely important for human health. Ocean water quality testing is conducted by the North Carolina Department of Environmental Health Shellfish Sanitation and Recreational Water Quality Section. They test for enterococcus bacteria (an indicator organism whose presence is correlated with that of others that can cause illness in humans) to determine if swimming advisories should be posted. Limits for enterococcus are based on the level of use a particular beach receives. A Tier 1 area is defined as receiving daily use during swimming season (April – September). Tier 1 beaches shall not exceed either: (1) A geometric mean of 35 enterococci per 100 ml of water, that includes a minimum of at least five samples collected within 30 days; or (2) A single sample of 104 enterococci per 100 ml of water. A Tier 2 area is defined as receiving on average three days of use per week during swimming season. The enterococcus level in a Tier 2 swimming area shall not exceed a single sample of 276 enterococci per 100 ml of water. A Tier 3 area is defined as receiving four days of use per month during swimming season. The enterococcus level in a Tier 3 swimming area shall not exceed two consecutive samples of 500 enterococci per 100 ml of water. The Atlantic Ocean beach of Zeke's Island is defined as a Tier 1 area and thus is sampled once per week during swimming season, and monthly otherwise (Figure 5.5 site S-18). Based on the data available on the Recreational Water Quality section website (2003-present) the beach side of Zeke's Island has not had any swimming advisories. The average enterococcus bacteria concentration for Site S18 (Figure 5.5) from 2003-2005 was 10.4 enterococci per 100 ml water. This is not surprising given that the ocean currents along Zeke's Island move quite rapidly. Thus any pollutants in the area are rapidly flushed.

B: Lower Cape Fear River Estuary Water Quality

a: Hydrology

The major hydrological influence for the Basin and tidal creeks of Zeke's Island is the lower Cape Fear River Estuary. The Cape Fear River watershed is the largest within the State encompassing 9,324 square miles (24,149 km^2) from Greensboro, N.C. to the coast (Figure 5.4).

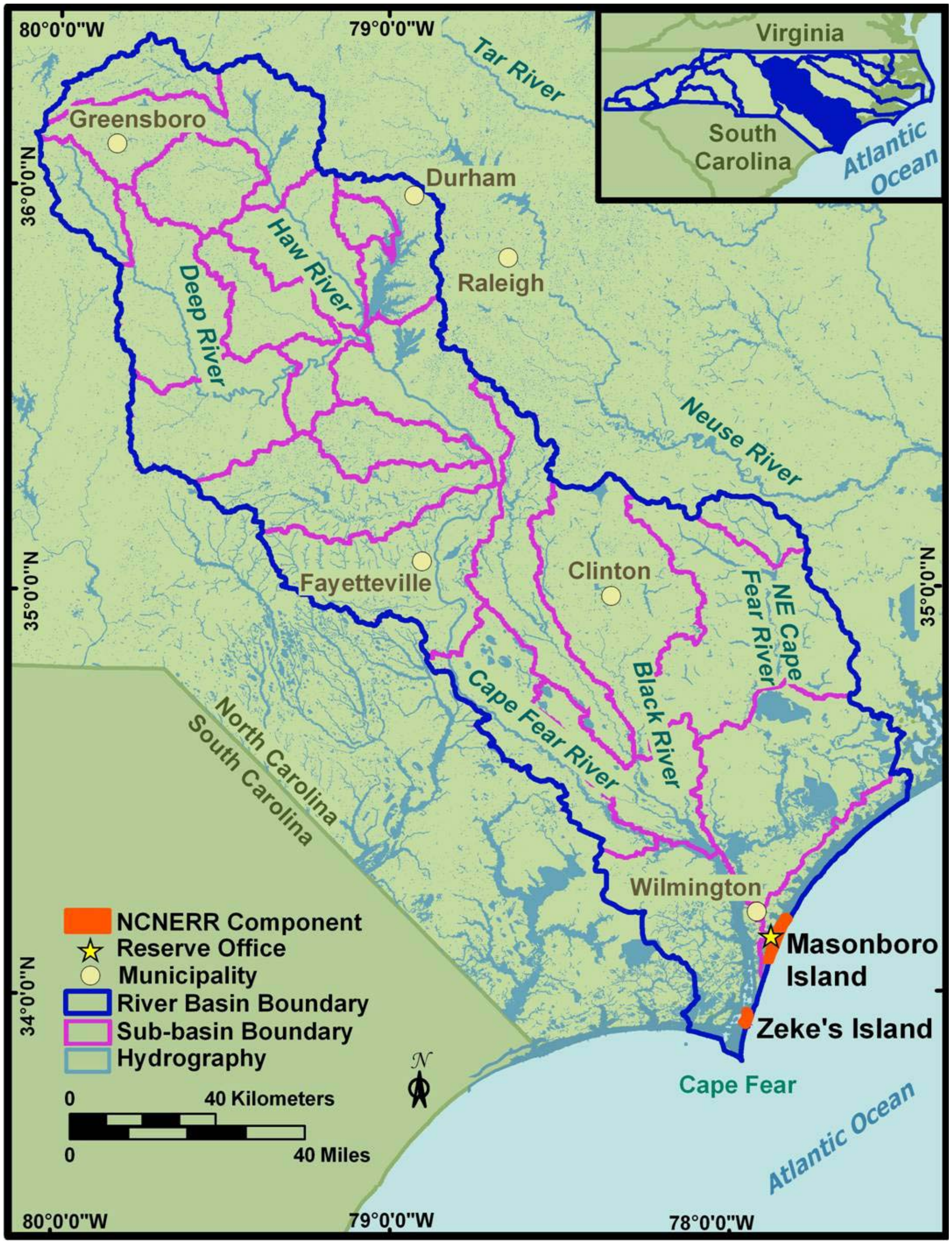


Figure 5.4: Cape Fear River Basin map.

The river supports a multitude of uses from agriculture, industry, power generation, and recreation. Since the last oceanic inlet closed in 1999, water within Zeke's Island has no direct exchange with the Atlantic Ocean. Thus, the water within Zeke's Island is directly dependent upon the water quality of the lower Cape Fear River Estuary. River water flows over the top of The Rocks during high tide. During extremely high tides and during periods of high river discharge, The Rocks are completely under water. Water exchange between the river and Zeke's Island also occurs through gaps where The Rocks have collapsed and no longer present a barrier to flow. The deepest water within Zeke's Island is only about 6 ft (1.8 m) and occurs in the tidal creeks. Tidal exchange in the Basin and tidal creeks is diurnal in nature and averages ~ 3.5 feet (1 m) in height. Strong winds from the south can enhance the water depths in the Reserve as they push water up the Cape Fear River.

b: Water Quality

The water quality of the Lower Cape Fear River Estuary is monitored by several entities working collaboratively within the Lower Cape Fear River Program. One of the stations monitored as part of this effort is located near Zeke's Island (Figure 5.5 site M23). Based on 2003-2004 findings, the water quality of the lower Cape Fear River Estuary near Zeke's Island was "good" in terms of dissolved oxygen concentrations, chlorophyll *a* concentrations, fecal coliform bacteria concentrations, and turbidity concentrations (Mallin et al. 2005) (Table 5.3). The criteria for a "good" rating are that N.C. State standards are not exceeded in more than 10% of all samples. A "fair" rating has samples exceeding North Carolina State standards in 11-25% of measurements, and a "poor" rating has samples exceeding the North Carolina State standard more than 25% of the time (North Carolina Division of Water Quality 2004). The North Carolina Division of Water Quality has designated the waters in Zeke's Island as shellfishing waters and high quality water. This means that shellfish can be harvested from the waters for human consumption. This is the most stringent water quality designation used by the North Carolina Division of Water Quality.

The four parameters mentioned above (dissolved oxygen, chlorophyll *a*, fecal coliform, and turbidity) are critically important because they serve as indicators of overall system health. Dissolved oxygen is needed by all estuarine organisms in order to survive. If there is not enough oxygen in the water, fish and other organisms may die. Chlorophyll *a* provides a measure of the amount of algae in a system which is an indicator for overall trophic status. Fecal coliform bacteria are indicators for other human illness causing organisms. Turbidity plays a big role in how much light passes through the water. When light does not penetrate very far in the water column, overall system productivity is hindered because the primary producers become light limited. This is not good for water quality because when estuarine primary producers are light limited they utilize less nutrients, increasing the nutrient load delivered downstream to the coastal ocean (see last paragraph in this section).

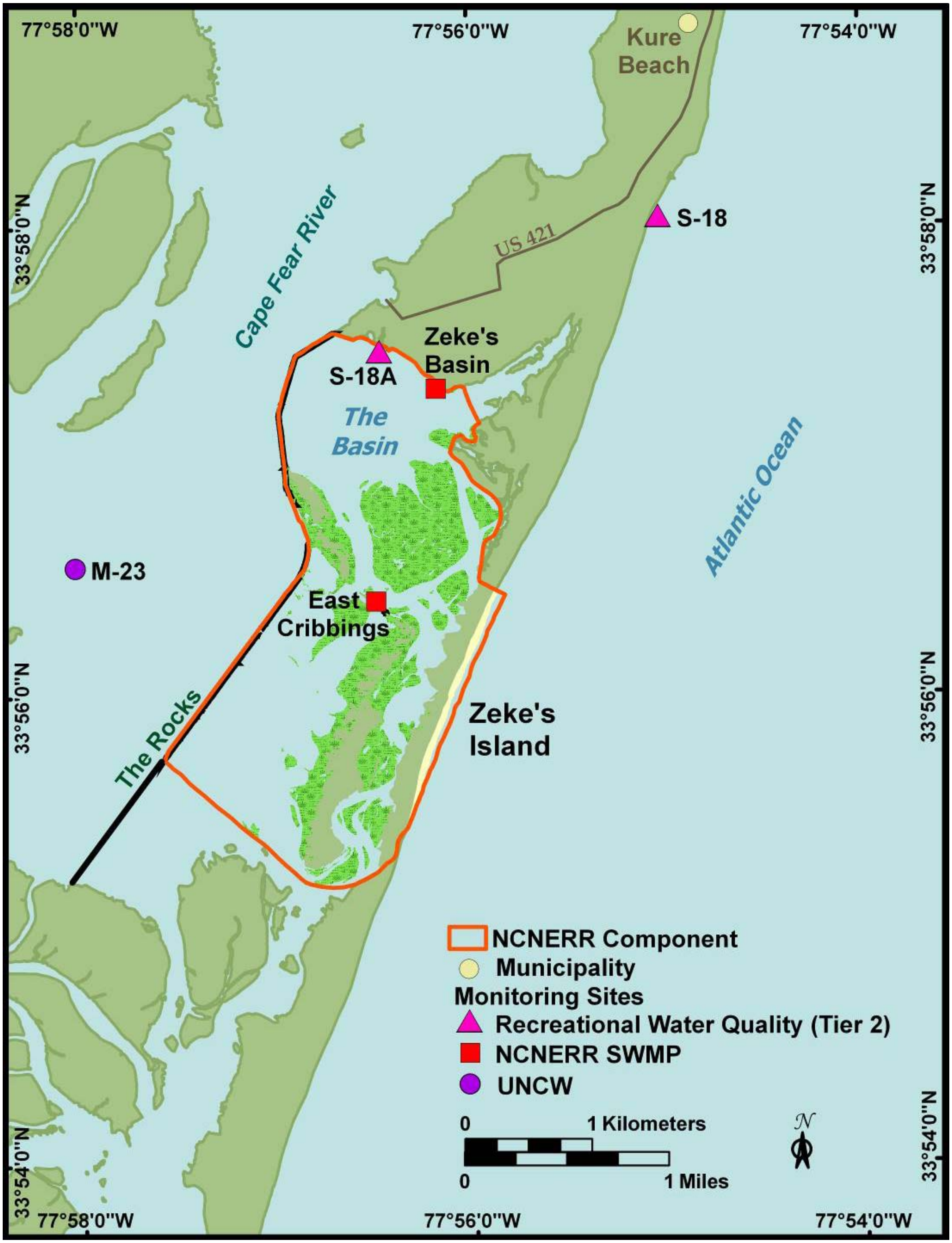


Figure 5.5: Water quality monitoring locations at Zeke's Island.

Table 5.3: Lower Cape Fear River water quality data averages from 2005

Parameter	Value
Temperature	19.7 °C
Salinity	21.7 psu
pH	7.9
Dissolved O_2	8.1 mg l^{-1}
Turbidity	7 NTU
Total Suspended Solids	12.8 mg l^{-1}
Light Attenuation	1.71 m^{-1}
Total Nitrogen	646 µg l^{-1}
Nitrate and Nitrite	133 µg l^{-1}
Ammonium	33 µg l^{-1}
Total Kjeldahl	506 µg l^{-1}
Total Phosphorus	28 µg l^{-1}
Othophosphate	15 µg l^{-1}
Chlorophyll a	3.4 µg l^{-1}
Fecal Coliform	6 CFU per 100ml
Aluminum	371 µg l^{-1}
Arsenic	4 µg l^{-1}
Cadmium	0 µg l^{-1}
Chromium	0 µg l^{-1}
Copper	9 µg l^{-1}
Iron	340 µg l^{-1}
Lead	0 µg l^{-1}
Mercury	0 µg l^{-1}
Nickel	11 µg l^{-1}
Zinc	4 µg l^{-1}
Data from Lower Cape Fear River Program Station M23	

The Recreational Water Quality section monitor at one Tier 2 location within the Zeke's Island basin (Figure 5.5 site 18A). Based on data from 2003 to present, there have not been any violations in this area and the average enterococci concentration was 24.4 enterococci per 100 ml water. However, during a period of high runoff associated with rainfall, a sample from this station in March 2003 had an enterococci reading of 324 enterococci per 100 ml water, demonstrating that the area is potentially susceptible to fecal contamination, and that all efforts to minimize runoff should be pursued.

Water quality within Zeke's Island has been monitored continuously by Reserve staff since 1994. Two SWMP water quality locations (Figure 5.5 site Zeke's Basin and East Cribbings) are equipped with continuously monitored water quality instruments made by Yellow Springs Instruments that measure: dissolved oxygen; pH; temperature; conductivity; salinity and turbidity. These locations have also been sampled monthly for nutrient (NH_4^+, NO_3^- and PO_4^{-3}) and chlorophyll *a* concentrations since 2002. The water quality within the basin is typically good. Table 5.4 provides the high, low and average for the measured water quality parameters at the SWMP stations at Zeke's Island.

Table 5.4: SWMP water quality data from Zeke's Island 2002-2006

	Zeke's Basin	East Cribbings
Parameter	**Range, Average**	**Range, Average**
Dissolved O_2 (%)	0 – 400, 93	10 – 300, 96
pH	6.6 – 9.3, 8	7 – 8.8, 8
Conductivity(mS/cm)	10 – 50, 34	8 – 50, 34
Salinity (psu)	5.5 – 34, 21	4 – 35, 21
Turbidity (NTU)	0 – 1000, 65	0 – 1000, 24
NH_4^+ (µg/l)	0 – 416, 116	0 – 415, 117
NO_3^- (µg/l)	0 – 444, 87	0 – 514, 105
PO_4^{-3} (µg/l)	0 – 136, 35	0 – 74, 21
Chlorophyll *a* (µg/l)	1 – 38, 6	1 – 21, 4

There are periods of high turbidity associated with wind and rain events, but the light scattering particles usually settle out quite rapidly once calmer conditions return. Salinity is variable, fluctuating based on runoff associated with rain events and tides. Strong tides push more saline water up the Cape Fear River making the salinity in the Zeke's Island Reserve higher. During drought periods, the salinity increases. During periods of heavy rain the salinity decreases. This was very evident during the passage of hurricane Ophelia in September 2005. Salinity after this storm decreased by about 4 ppt and remained depressed for the rest of September due to the influx of rain water associated with Ophelia (Figure 5.6).

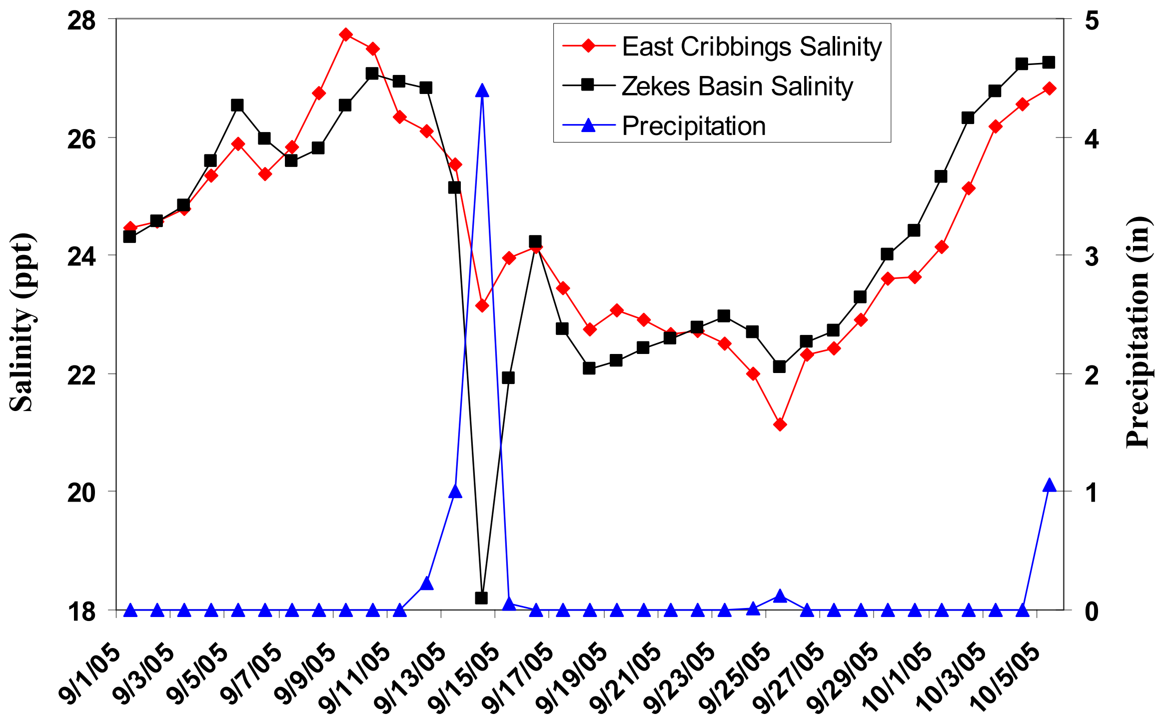


Figure 5.6: Daily averaged salinity and precipitation at Zeke's Basin and East Cribbings before, during (9-13-05 to 9-15-05), and after hurricane Ophelia. Precipitation data was measured at the weather station located on Masonboro Island.

Figure 5.7 shows the average annual temperature, salinity, dissolved oxygen, and turbidity measured at East Cribbings since 1994 and Zeke's Basin since 2002. Most of the parameters have remained fairly stable since 1994. This implies that the water quality within the Reserve has also been fairly stable and has been "good" since monitoring was initiated by Reserve staff. The low dissolved oxygen value from 1994 at East Cribbings is likely an artifact as data collection did not start that year until May. Typically the summer months have lower dissolved oxygen values due to the higher water temperatures. Oxygen values at both SWMP stations have remained pretty close to 8 mg l^{-1} throughout the dataset.

The two sites demonstrate some differences in overall turbidity values. The Zeke's Basin SWMP station generally had higher turbidity values compared to the East Cribbings SWMP station (Figure 5.7 and Table 5.4). The most probably cause for this is the differences in environmental conditions between the two stations. Zeke's Basin is a shallow sampling station that is impacted by a large wind fetch from the southwest. These two factors combine to make the sediments at the Zeke's Basin SWMP station easily resuspendable. These resuspended sediments cause high turbidity values. East Cribbings is a deeper more sheltered area. The highest annual turbidity average at East Cribbings (35 NTU) occurred in 1996. This is also the year the area was impacted by a series of fall hurricanes (Table 5.2). Turbidity values were elevated by these storms and their resultant runoff causing this high value. There also appears to be a general trend for increasing turbidity at East Cribbings since 2001 (Figure 5.7). This trend is unexplainable at this time, but staff has noticed that the site appears to be getting shallower. If this is what is going on, then increased turbidity would be expected because the shallower the bottom the more susceptible it is to sediment resuspension.

The yearly averaged salinity values at the East Cribbings SWMP station have been generally decreasing since 1994 at a rate of 0.5 ppt yr^{-1}. Like the turbidity trend above, it is hard to assign a direct cause for this change in salinity. One possibility is the closing of New Inlet. New Inlet was in the process of closing when the SWMP station at East Cribbings was installed in 1994. The inlet finally closed completely in 1999. This effectively cut the tidal creeks of Zeke's Island off from the Atlantic Ocean. As a result, salinity levels would be expected to decrease as the only water source would be the estuarine waters of the Cape Fear River. The slow pace of the decrease may be associated with residual salinity contained in the marshes and sediments of Zeke's that is slowly being leached. Another possibility would be a gradual increase in the amount of rain received by the Reserve, but this hypothesis is not supported by the precipitation data. The Cape Fear River has been deepened over this time period as well to support shipping activity at the State port in Wilmington, N.C. This could enhance the flow of freshwater downstream and be contributing to the salinity decrease as well. The Zeke's Basin dataset is not yet long enough to observe whether this decrease in salinity is occurring there as well. As years of data are accrued at this site, it is expected a similar trend will emerge.

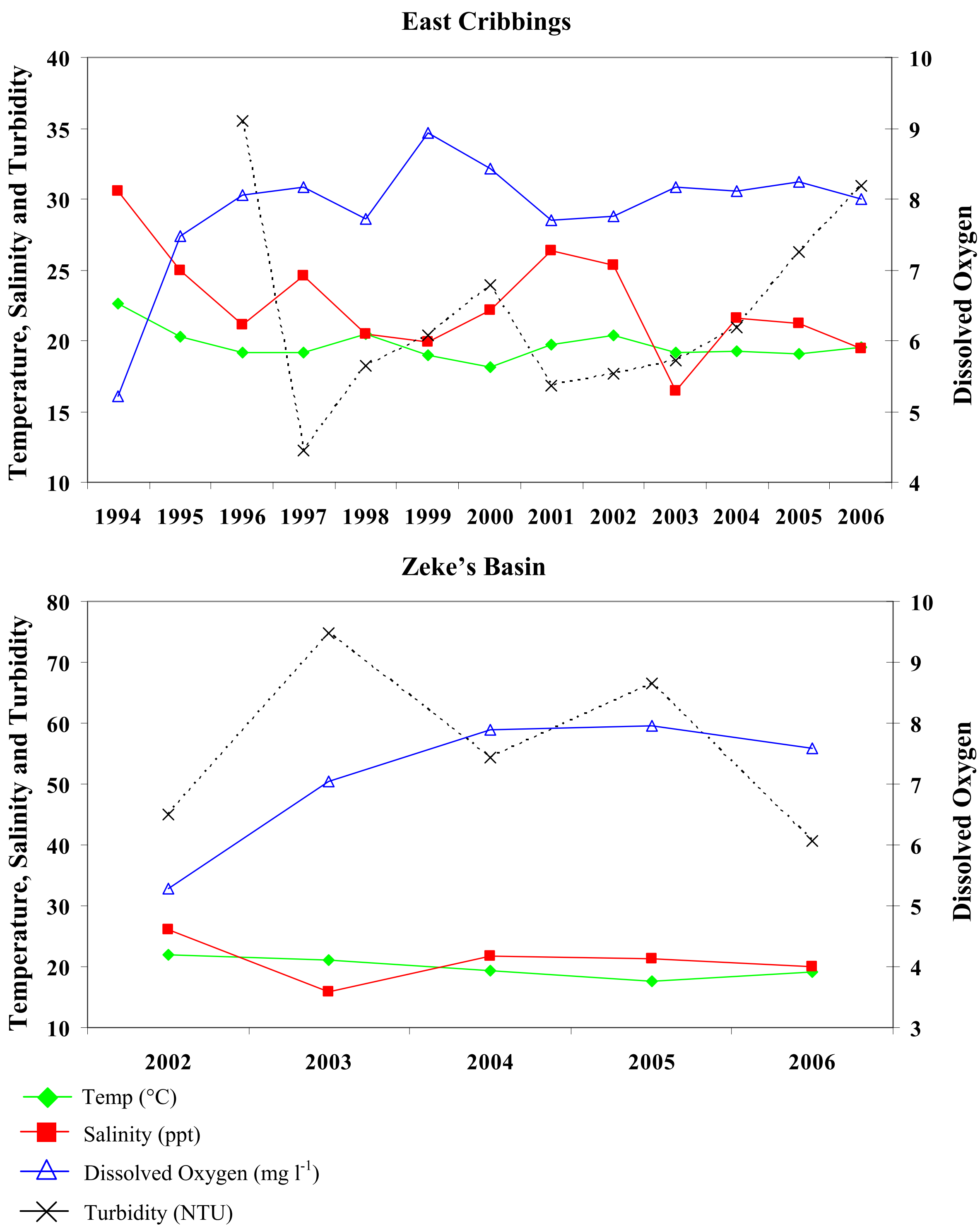
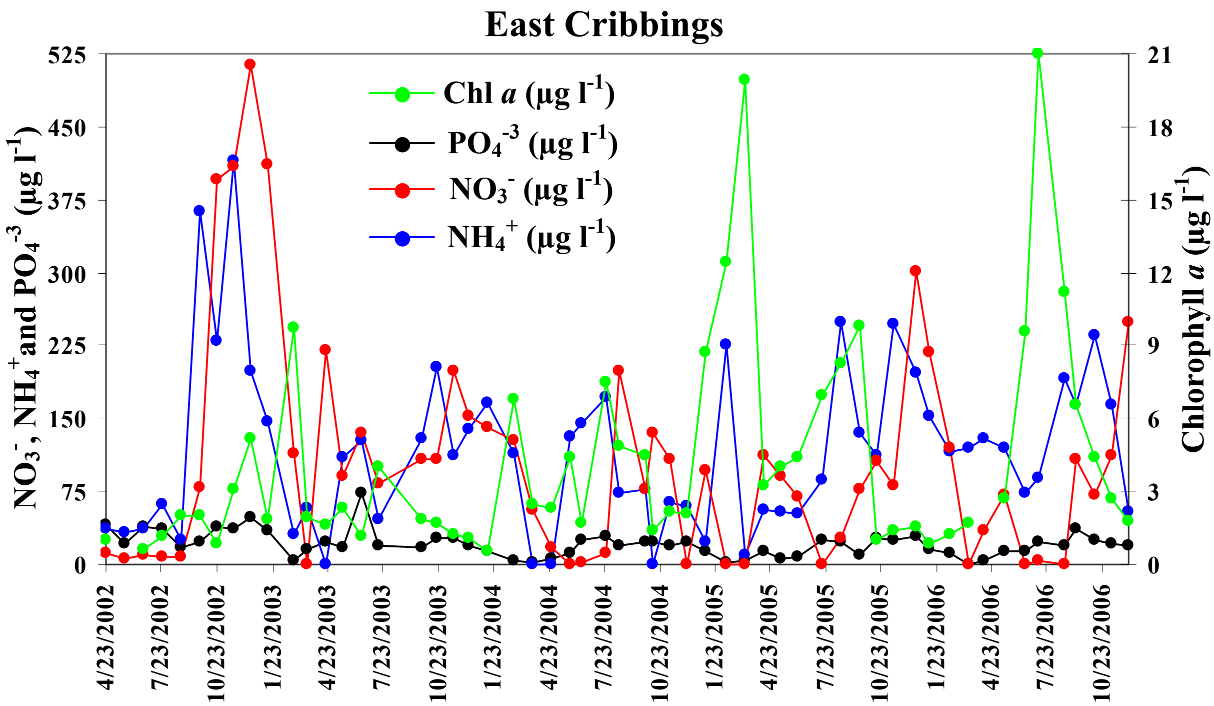


Figure 5.7: Yearly averaged physical-chemical SWMP data from Zeke's Island.

Figure 5.8 shows the nutrient (NO_3^-, NH_4^+, PO_4^{-3}) and Chlorophyll *a* concentrations in the Reserve since 2002 measured monthly as part of the SWMP. The range and average for the nutrient and Chlorophyll *a* values are included as part of Table 5.4. Nutrient pulses observed at Zeke's Basin were also observed at East Cribbings (Figure 5.8). This suggests that the pulses are associated with riverine input which affects both stations and not local runoff which would affect Zeke's Basin more than East Cribbings (since it is closer to land). NO_3^- and NH_4^+ tended to occur in similar concentrations at both stations (Figure 5.8 and Table 5.4). Pulses of both NH_4^+ and NO_3^- were frequently observed during all parts of the year. Similar pulses in PO_4^{-3} were not observed. PO_4^{-3} levels were usually quite low. Over the entire dataset, Zeke's Basin tended to have slightly higher PO_4^{-3} levels then East Cribbing (Table 5.4). Although the dataset is still quite limited in length, since 2002 there has not been any increase in the overall nutrient concentration at Zeke's Island. The average dissolved inorganic nitrogen (NH_4^+ and NO_3^-) to Phosphorus ratio is 13. Compared to Redfield ratios this means that Zeke's Island is nitrogen deficient (Redfield 1958). This suggests that the nutrient most limiting primary producer growth at Zeke's Island is nitrogen.

Chlorophyll *a* levels within the Reserve do not track the nutrient pulses (Figure 5.8). Chlorophyll levels tended to spike about 1 month after nutrient pulses (Figure 5.9). This lag time suggest that the phytoplankton at Zeke's Island may not be able to rapidly respond to nutrient pulses. This implies that something else besides nutrients may be limiting the growth of phytoplankton within Zeke's Island. The likely limiting factor is light availability. The water at Zeke's Island is often very cloudy, preventing light penetration. Since 2004, NCNERR staff has been measuring Secchi depths as part of routine SWMP activities. On average, the Secchi depth at Zeke's Island is 1.6 ft (0.5 m). This means that on average only the top 0.5 m of the water column receives enough light to sustain photosynthetic organisms. Chlorophyll *a* levels were negatively correlated with dissolved inorganic nitrogen ($p < 0.05$). This corroborates the hypothesis that the primary producers at Zeke's Island are light and not nutrient limited. These factors suggest that Zeke's Island is probably not serving as an efficient nutrient filter. Nutrients introduced into the Reserve, most likely pass through before being utilized. The interaction between nutrients versus light limitation for Zeke's Island primary producers is a knowledge gap that needs to be addressed by future research projects.



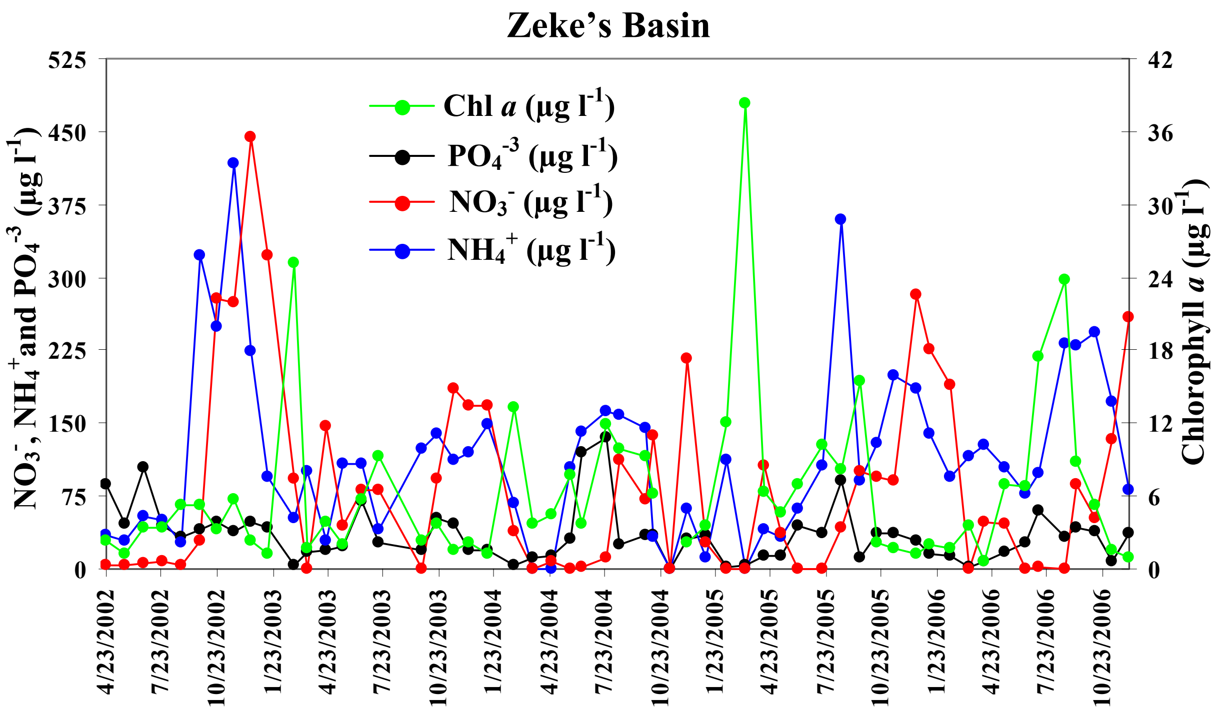


Figure 5.8: Monthly nutrient and Chlorophyll a data for East Cribbings and Zeke's Basin SWMP stations.

5.6: Habitat Types

A primary objective of SWMP Phase 3 is to evaluate changes over time in estuarine habitats and coastal land cover. To accomplish this, the types and locations of habitats within the Reserve must be periodically quantified. The habitat types of Currituck Banks were initially characterized in 1994. This effort used a very general classification system that only broke habitats down into very broad categories. These habitat types included subtidal softbottoms, tidal creeks, intertidal mud and sand flats, salt marshes, rock jetty, maritime forest, dunes and beaches (Table 5.5). Figure 5.9 shows the resultant map from this effort.

Table 5.5: Zeke's Island 1994 habitat classifications

Habitat	Description
Subtidal softbottoms	Open sand or mud flats that never get exposed at low tide.
Tidal creeks	Open water feeder creeks between the basin and historic inlets.
Intertidal mud and sand flats	Open sand or mud flats that are submerged at high tide and exposed at low tide.
Salt marshes	Low and high fringing areas that are persistently wet.
The rocks	Remains of a rock jetty on the western boundary of Zeke's and in the area known as the Cribbings.
Evergreen maritime forest	Shrub forest areas on the upland islands.
Dunes	Area above the high tide line on the barrier spit along the eastern boundary of Zeke's.
Sandy beaches	Intertidal and supratidal areas of the barrier spit along the eastern boundary.

However, this assessment provided only minimal information regarding habitat types and function. To more accurately and methodologically account for the various habitat types within the Reserve components, in 2005 NCNERR participated as a pilot Reserve for the NERRS habitat and land use classification system. This effort categorized the habitats within the Reserves using a much improved classification system (Appendix 4).

The updated Zeke's Island habitat map based on this approach is presented at the Subclass level in Figure 5.10. Areal statistics for habitat occurrence were calculated from the digital classification data and are provided as acreage and the percentage of total acres mapped for each habitat subclass (Table 5.6). Subtidal areas were not included in this assessment. Visual observations were made during field surveys to document predominant plant species for each habitat subclass. These data provide a framework for conducting more in-depth inventories of vegetation composition and conditions. Habitat subclasses at Zeke's Island are described in the following paragraphs, with representative photographs presented in Appendix 4.

A point of clarification is required regarding the naming convention for the upland islands found within the Zeke's Island Reserve component. Two upland islands are present within the Reserve, North Island and Zeke's Island (Figure 5.1). To prevent confusion between the entire Zeke's Island Reserve and the upland island that shares the same name, the Reserve is always implied by the name Zeke's Island. The upland island within the Reserve will be called the upland Island Zeke's.

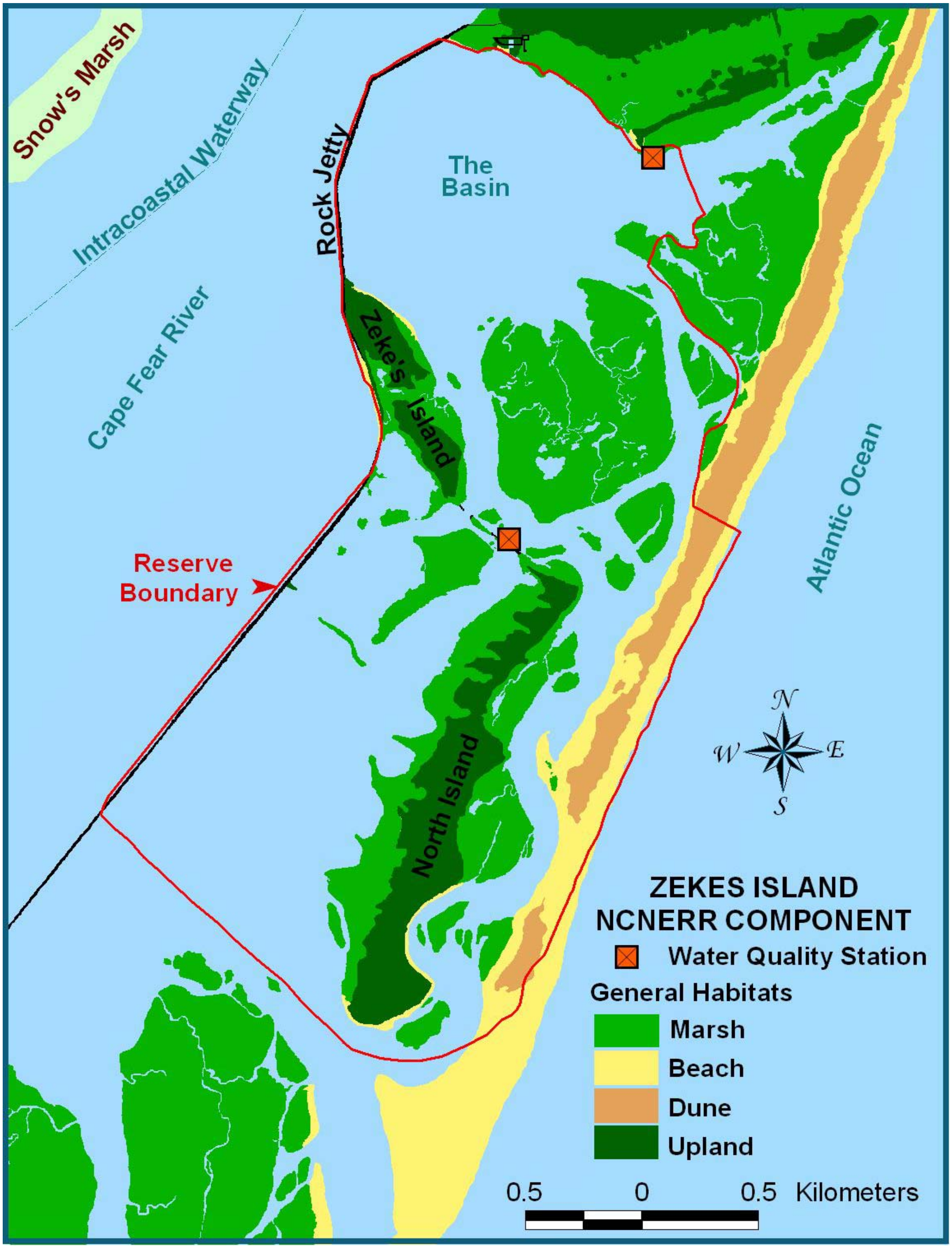


Figure 5.9: Habitat map from 1994 for Zeke's Island.

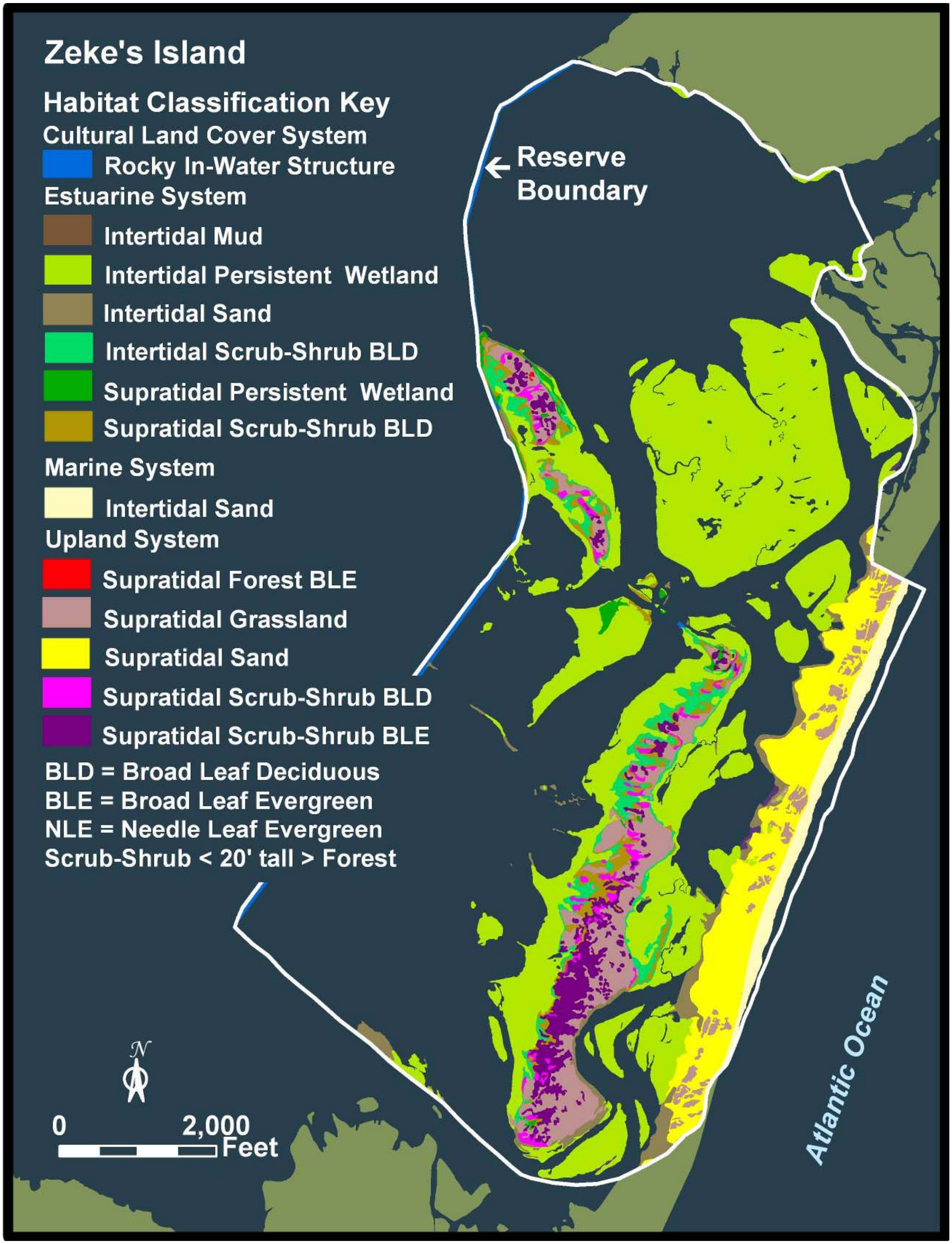


Figure 5.10: Zeke's Island 2004 habitat classification presented at the subclass level.

Table 5.6: Zeke's Island 2004 habitat classifications areal statistics

Habitat Subclass	Area (Acres)	% of Total
Estuarine Intertidal Persistant Wetland	365.81	56.13
Upland Supratidal Sand	77.93	11.96
Upland Supratidal Grassland	64.90	9.96
Upland Supratidal Scrub-Shrub Broad Leaf Evergreen	29.27	4.49
Estuarine Intertidal Scrub-Shrub Broad Leaf Deciduous	26.57	4.08
Estuarine Intertidal Sand	25.64	3.93
Marine Intertidal Sand	21.85	3.35
Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous	20.66	3.17
Upland Supratidal Scrub-Shrub Broad Leaf Deciduous	9.74	1.49
Estuarine Supratidal Persistant Wetland	5.04	0.77
CLC Rocky In-water Structures	2.89	0.44
Estuarine Intertidal Mud	1.35	0.21
Upland Supratidal Forest Broad Leaf Evergreen	0.14	0.02
Total Mapped Habitat Area	**657.49***	**100**
* Subtidal areas not mapped		

- The largest habitat subclass at the Zeke's Island Component was Estuarine Intertidal Persistant Wetland, with 365 acres and 56% of the total mapped area. This subclass is primarily expanses of Smooth Cordgrass (*Spartina alterniflora)* that are located in the center portion of the Reserve and along the fringes of both North Island and the upland Island Zeke's.

- The Upland Supratidal Sand subclass was second in coverage, with 78 acres for 12% of the total mapped habitat. These are open sandy areas, commonly known as "Sand Dunes", with $\leq$ 30% vegetative cover. They are adjacent to the Atlantic Ocean beach, along the eastern boundary of the Reserve.

- The third most prevalent subclass was Upland Supratidal Grassland, with 65 acres and 10% of the total mapped area. These areas have $\geq$ 30% vegetative cover with a mix of perennial beach grasses, including Salt Meadow Hay (*Spartina patens)*, Sea Oats (*Uniola paniculata*), Inland Saltgrass (*Distichlis spicata*) and various species of *Panicum.*

- The fourth largest subclass was Upland Supratidal Scrub-Shrub Broad Leaf Evergreen with 30 acres and 5% of the total habitat. This subclass occurred throughout the central corridors of North Island and the upland Island Zeke's. Species present include Yaupon (*Ilex vomitoria*), Wax Myrtle (*Morella cerifera* or *Myrica cerifera*), and Laurel Oak (*Quercus laurifolia*). A small amount of Eastern Red Cedar (*Juniperus virginiana*), a needle leaf evergreen, is also inhabits these areas.

- Estuarine Intertidal Scrub-Shrub Broad Leaf Deciduous subclass encompassed 27 acres (4% of total habitat) with Sea Ox-eye (*Borrichia frutescens*) the dominant species. This subclass bordered the inland edge of the Estuarine Intertidal Persistant Wetland, with extensive areas and smaller stands, respectively, in northern and southern North Island. Large swaths were also found along western and southern portions of the upland Island Zeke's.

- Three subclasses each represented 3 – 4% of the total mapped area. Estuarine Intertidal Sand (26 acres) consists of all sandy intertidal areas within the estuary, including the western edge of the barrier spit along the Atlantic Ocean. Marine Intertidal Sand (22 acres) was found along the ocean side of the Reserve. This subclass consists of the bare sand between the high and low tide lines. Stands of Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous (21 acres) were distributed across North Island and the upland Island Zeke's, as well as in the supratidal marsh between the two islands. Sea Ox-eye (*Borrichia frutescens*) is dominant, with a variety of companion species of grasses.

- Approximately 1% of the total habitat is covered by each of two subclasses. Upland Supratidal Scrub-Shrub Broad Leaf Deciduous (10 acres) was found in the upland areas of both North Island and the upland Island Zeke's. Vegetation consists of a mix of shrubs, especially Marsh Elder (*Iva frutescens*), and Grounsel Tree (*Baccharis halimifolia*). The Estuarine Supratidal Persistant Wetland (5 acres) subclass contains Salt Meadow Hay (*Spartina patens*), Inland Saltgrass (*Distichlis spicata*), and Black Needle Rush (*Juncus roemarianus*).

- Three subclasses each represented < 0.5% of the total habitat. Cultural Land Cover Rocky In-Water Structures (3 acres) refers to the rock wall jetty that defines the western boundary of the Reserve. Estuarine Intertidal Mud (1 acre) consists of two long muddy banks on the western edge of the barrier spit adjacent to the Atlantic Ocean. Upland Supratidal Forest Broad Leaf Evergreen (0.1 acres) characterizes a stand of mature Live Oak (*Quercus virginiana*) on the upland Island Zeke's that is approximately 75' in diameter.

5.7: Plants

The plant communities present within the Zeke's Island area are consistent with those of other barrier islands found in this part of the country. The dominant plant species for each habitat subclass are listed in the preceding section. The Natural Heritage Program has recognized two plant species within New Hanover County as significant (Table 5.7). Seabeach Amaranth (*Amaranthus pumilus*) (Figure 5.11) is listed as a threatened species on both the federal and state level and may be

Figure 5.11: Seabeach Amaranth

found in Zeke's Island on the foredune areas of the marine intertidal sand areas. Dune Bluecurls (*Trichostema sp*) (Figure 5.12) is considered a significantly rare species on the state level, with a range limited to North Carolina and adjacent states. Dune Bluecurls may be found at Zeke's within the marine intertidal sand areas and in the upland areas of the islands. However, neither of these plants was observed during the ground-truthing exercise as part of the field mapping exercises.

Figure 5.12: Dune Bluecurls

5.8: Animals

A: Invertebrates and Zooplankton

The depositional basin and tidal creeks of Zeke's Island are home to a vast array of invertebrate species. Crabs, shrimp, clams, tunicates, and oysters are commonly seen. The sediments support marine worms, snails and many other infauna species. All these organisms are extremely important because they are used as food items by many species of fish.

B: Fishes

Many fish species utilize the waters of Zeke's Island. Ross and Bichy (2002) published a thorough sampling of the ichthyofauna inhabiting Zeke's Island. This work identified 103 different species of fish utilizing Zeke's Island. The waters within Zeke's Island are an important nursery area for many species of fish including Flounder (*Paralichthys dentalus* and *Paralichthys lethostigma*), Mullet (*Mugil cephalus*), and Speckled Trout (*Cynoscion nebulosus*). Stingrays and small sharks have also been found in the Reserve.

C: Reptiles and Amphibians

Only a few reptile species have been documented at Zeke's Island. Sea turtles nest in the marine intertidal sand areas. The vast majority of these nests are from Loggerhead Sea Turtles (*Caretta caretta*). However, other marine turtle species including the Green Sea Turtle *(Chelonia mydas)* have been occasionally observed. Diamondback Terrapins (*Malaclemys terrapin centrata*) (Figure 5.13) are found within the marsh, and also nest near the primary dune line. The turtles and turtle eggs of all these species were prized for their meat in the 1700 and 1800's (McCauley 1945; Carr 1952).

Figure 5.13: Diamondback Terrapin on an estuarine intertidal mudflat.

Consequently, populations were decimated. Although they are all now protected from harvest (Table 5.7), populations have been slow to rebuild and the turtle numbers are still low. Other reptiles including Rat Snakes (*Elaphe obsolete*), Glass Lizards (*Ophisaurus ventralis*) and Six-liner Racerunners (*Cnemidophorus sexlineatus*) have been observed in the upland habitat areas at Zeke's Island (Atkinson et al 1998). It is likely that other snake and lizard species are occasionally transplanted to the Reserve from the mainland and just have not yet been documented. A full survey of upland fauna species is a gap that needs to be addressed.

Table 5.7: Species of special concern in and near Zeke's Island

State Status Codes: E = Endangered, T = Threatened, SC = Special Concern, SR = Significantly Rare, L = range limited to North Carolina and adjacent states.

Federal Status Codes: E = Endangered, T = Threatened, FSC = Federal Special Concern.

Major Group	Scientific Name	Common Name	State Status	Federal Status
Vascular Plants	*Amaranthus pumilus*	Seabeach Amaranth	T	T
Vascular Plants	*Trichostema sp*	Dune Bluecurls	SR-L	FSC
Bird	*Charadrius melodus*	Piping Plover	T	T
Bird	*Charadrius wilsonia*	Wilson's Plover	SR	-
Bird	*Egretta caerulea*	Little Blue Heron	SC	-
Bird	*Egretta thula*	Snowy Egret	SC	-
Bird	*Egretta tricolor*	Tricolored Heron	SC	-
Bird	*Pelecanus occidentalis*	Brown Pelican	SR	-
Bird	*Rynchops niger*	Black Skimmer	SC	-
Bird	*Sterna antillarum*	Least Tern	SC	-
Bird	*Sterna hirundo*	Common Tern	SC	-
Bird	*Haematopus palliatus*	American Oyster Catcher	SR	-
Bird	*Catoptrophorus semipalmatus*	Willet	SR	-
Reptile	*Caretta caretta*	Loggerhead	T	T
Reptile	*Chelonia mydas*	Green Turtle	T	T
Reptile	*Crotalus adamanteus*	Carolina Diamondback Terrapin	SC	-
Fish	*Evorthodus lyricus*	Lyre Goby	SR	-
Mammal	*Trichechus manatus*	West Indian Manatee	E	E

Data from the North Carolina Natural Heritage Program

D: Birds

Zeke's Island contains ideal bird habitat for many types of birds. Wading birds like Herons and Egrets and several duck species including Mallards, Pintails and Black, heavily utilize the tidal creeks and intertidal flats for feeding. The marine intertidal sand areas support many species of marine shore/wading birds. In addition, the uplands provide habitat for many species of songbird. Atkinson et al. (1998) documented over 260 species during their surveys at Zeke's Island. Several of these species are of special concern (Table 5.7).

E: Mammals

There is a wide array of mammals present within the Reserve area. The 1998 North Carolina National Estuarine Research Reserve Management Plan has listed the following mammals as being observed within Zeke's Island: Opossums (*Didelphis virginiana*), Raccoons (*Procyon lotor*), Grey Foxes (*Urocyon cinereogentus*), Marsh Rabbits (*Sylvilagus palustris*), River Otters (*Lontra Canadensis*), and Cotton Rats (*Sigmodon hispidus*). North Island has the most upland habitat, and due to its size, and vegetative cover, it may provide the greatest opportunity for observing mammals. (Atkinson et al, 1998). The only mammal of special concern that occurs within Zeke's Island is an occasional visit by the West Indian Manatee (*Trichechus manatus*) (Table 5.7). Manatees are a rare visitor to the coastal waters of North Carolina, most frequently being seen in late summer. A full species list is included as Appendix 5.

5.9: Invasive Species

The only documented invasive species within the Zeke's Island at current time are the European Poplar (*Populus nigra L.*) and Beach Vitex (*Vitex rotundifolia*) (Figure 5.14). Beach Vitex is particularly detrimental because it does not provide the same level of habitat quality or defense against erosion compared to natural dune communities. Many other undiscovered invaders are likely present at Zeke's Island. Zeke's Island is susceptible to invasion by Nutria (*Myocaster coypus*), Tamarisk Tree (*Tamarix ramosissima*), Russian Olive (*Elaeagnus angustifolia*), etc. The shipping channel that passes through the Cape Fear River along Zeke's Island is a potential source for water borne invaders from around the world transported in the ballast water of ocean going vessels. Assessing the number and type of invasive flora and fauna is a priority for future research/stewardship activities at Zeke's Island.

Figure 5.14: Beach Vitex

5.10: Stressors

The Zeke's Island Reserve is exposed to a variety of stressors, both natural and anthropogenic (man-made). Natural stressors include hurricanes, inlet migration/closure, salinity fluctuations and sedimentation. Anthropogenic stressors include pollution, nutrient loading, habitat disruption and altered land use, and public use of the Reserve. A few of the major stressors are highlighted in the following sections.

A: Pollution/eutrophication

Eutrophication leads to excessive phytoplankton production. This can lead to a multitude of water quality problems including hypoxia, decreased light penetration, altered community composition, loss of seagrass beds, and decreased fish and shellfish populations. Recovery from eutrophication can take long periods of time even if the causes of the eutrophication are immediately halted (Mallin et al. 2000b, Mallin et al. 2001). Pollution can cause immediate effects if the pollutant is highly toxic, or its effect can occur over many years as pollutant loads gradually increase. At Zeke's increases in nutrients and pollutants are very likely possibilities given the large watershed of the Cape Fear River.

The North Carolina Department of Environment and Natural Resources - Division of Water Quality publishes a Basinwide Water Quality Plan for each of the major rivers in North Carolina every five years. This plan divides the river watershed into smaller subbasins for assessments. The Cape Fear River Subbasin 03-06-17 contains the lower Cape Fear estuary, including the portion of the river bordering the Reserve property. Within this subbasin there are 49 permitted dischargers; half of which discharge directly into the Cape Fear River. Ten of these are major dischargers (>1 million gallons (3,785,411 L) per day), with the largest including International Paper, and the City of Wilmington's North Side Waste Water Treatment Plant and South Side Waste Water Treatment Plant. (North Carolina Division of Water Quality 2005)

The Cape Fear River estuary was listed as partially supporting by the North Carolina Division of Water Quality due to low levels of dissolved oxygen. This means that the river was only partially capable of supporting the best uses suited to it. The impacts from waste water treatment plants discharges within the subbasin and non-point source pollution are suspected to be contributors to the impairment. Possible sources of non-point pollution include marinas, canal systems and septic systems (North Carolina Division of Water Quality 2005). Over the past year the more than 3,000,000 gallons (11,356,235 L) of untreated sewage were discharged by the City of Wilmington waste water treatment plants due to distribution system failure. Many other pollution impacts likely go undocumented. These increased discharges associated with the decrease in vegetated land cover noted above could dramatically lower the water quality within the Cape Fear River and Zeke's Island. Despite these issues, the SWMP monitoring has not yet picked up a declining water quality signal. This implies one of two things: 1) the Cape Fear River is still serving as an efficient filter for nutrients and pollution in which case the pollutant load is attenuated before it gets to Zeke's Island; or 2) the filtering capacity of the river has been overcome. In this scenario, the river is attenuating all the pollutants physically/biologically possible. This would explain the steady state conditions of the SWMP monitoring. In this case the river is no longer serving as a nutrient/pollution buffer but basically as a rapid one way waste pipeline to the coastal ocean. If the second option is indeed what is occurring, then the coastal Atlantic Ocean is where water quality changes would be first detected. Future research is needed on the coastal ocean within the Cape Fear River discharge zone to look for this. To try and address this NCNERR is seeking a partnership with NOAA's Coastal Ocean Research and Monitoring Program. This program has been looking at water quality within the coastal margin of N.C. since 2000. Together, we would place instrumentation at the mouth of the Cape Fear River to investigate the water quality at the river/ocean interface.

B: Altered Land Use

The type of land cover present is a critical issue because how the land is used and the type of cover on it has large impacts on its ability to sequester nutrients and pollution rather than convey them to surface waters. Natural land covers with vegetative cover such as forest and marsh have large buffering capacities. They tend to trap nutrients and sediment prior to them entering surface waters. Developed land tends to have very little capacity to absorb nutrients and pollution. This is because developed land has increased impervious surfaces such as roofs, roads, and parking lots. These surfaces do not let water infiltrate the ground and high percentages of impervious surfaces have been correlated with degraded water and sediment quality (Holland et al. 2004; Mallin et al. 2000b). Consequently, stormwater runs off these surfaces picking up whatever contaminants and nutrients are on them and rapidly moves these materials to surface waters (Mallin et al. 2000b; Mallin et al. 2001).

To assess the amount of change within the Zeke's Island watershed, land cover types were evaluated for the two most recent years that data were available, 1991 and 1997. Land cover information was obtained for coastal North Carolina from NOAA's Coastal Change Analysis Program. This analysis was conducted on the lower Cape Fear River watershed as designated by the United States Geologic Survey (Hydrologic Cataloguing Unit 03030005). See Appendix 4 for detailed methodology. Figure 5.15 shows the land cover maps for 1991 (panel a) and 1997 (panel b).

For clarity the changes that occurred between 1991 and 1997 have been grouped into three categories. The first category is a decrease in vegetation cover (of any type). The second is an increase in vegetation cover (of any type) and the third is a change from one type of non-vegetated cover to another (neither an increase of decrease of vegetation). The decrease in vegetation cover category includes all areas where the Land Cover changed between 1991 and 1997 to a class that characterizes conditions with generally less plant cover or biomass. Examples of this category are a transition from Forested to Grassland or Scrub-shrub to Low Density Development. The increase in vegetation cover category was assigned to all areas where the Land Cover changed to a class that represents generally greater plant cover or biomass. Examples of this category are succession of grassland to Scrub-Shrub and Scrub-Shrub to Forested. The change in non-vegetated cover category designates all areas that had different non-vegetated land cover classes in 1991 and 1997. Examples included water to unconsolidated shore, unconsolidated shore to bare land and bare land to low-density developed. Figure 5.16 and Table 5.8 presents only these changed areas between 1991 and 1997.

Table 5.8: Change in land cover from 1991 to 1997 in the Zeke's Island watershed

Category	Acres	% of total
Total mapped area	672,098	n/a
Water area	37,530	5.6
Total land area	634,568	94.4
Decrease in vegetative cover	36,301	5.7
Increase in vegetative cover	28,690	4.5
Change from one unvegetative cover to another	297	0.05
Unchanged land cover	569,280	89.7
Net loss of vegetation = 1.2%		
Percent of land area with changed cover types = 10.3%		

Changes that occurred between 1991 and 1997 affected 10.3% of the watershed. The increase in vegetated conditions (4.5%) was mainly associated with succession of Grassland to Scrub/Shrub and Scrub/Shrub to Evergreen Forest, primarily in a band across the southern watershed, near the Green Swamp. Conversion of Evergreen Forest to Scrub/Shrub and Grassland (5.7%) in the southwestern portion of the watershed accounted for most of the decrease in vegetated conditions. The net loss in vegetative cover between 1991 and 1997 was 7,611 acres representing 1.2% of the watershed.

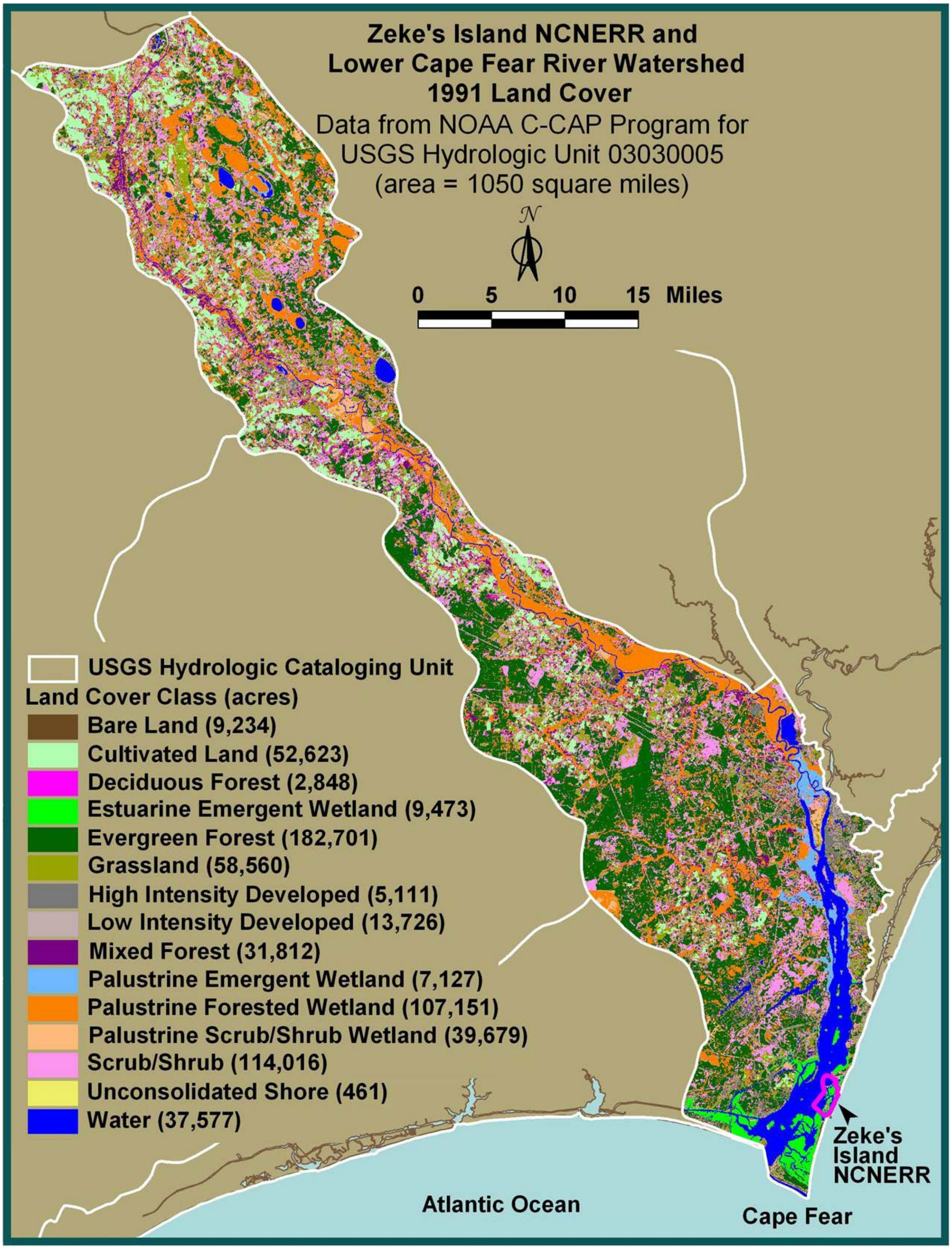


Figure 5.15a: Land use classification from 1991 in the Zeke's Island watershed.

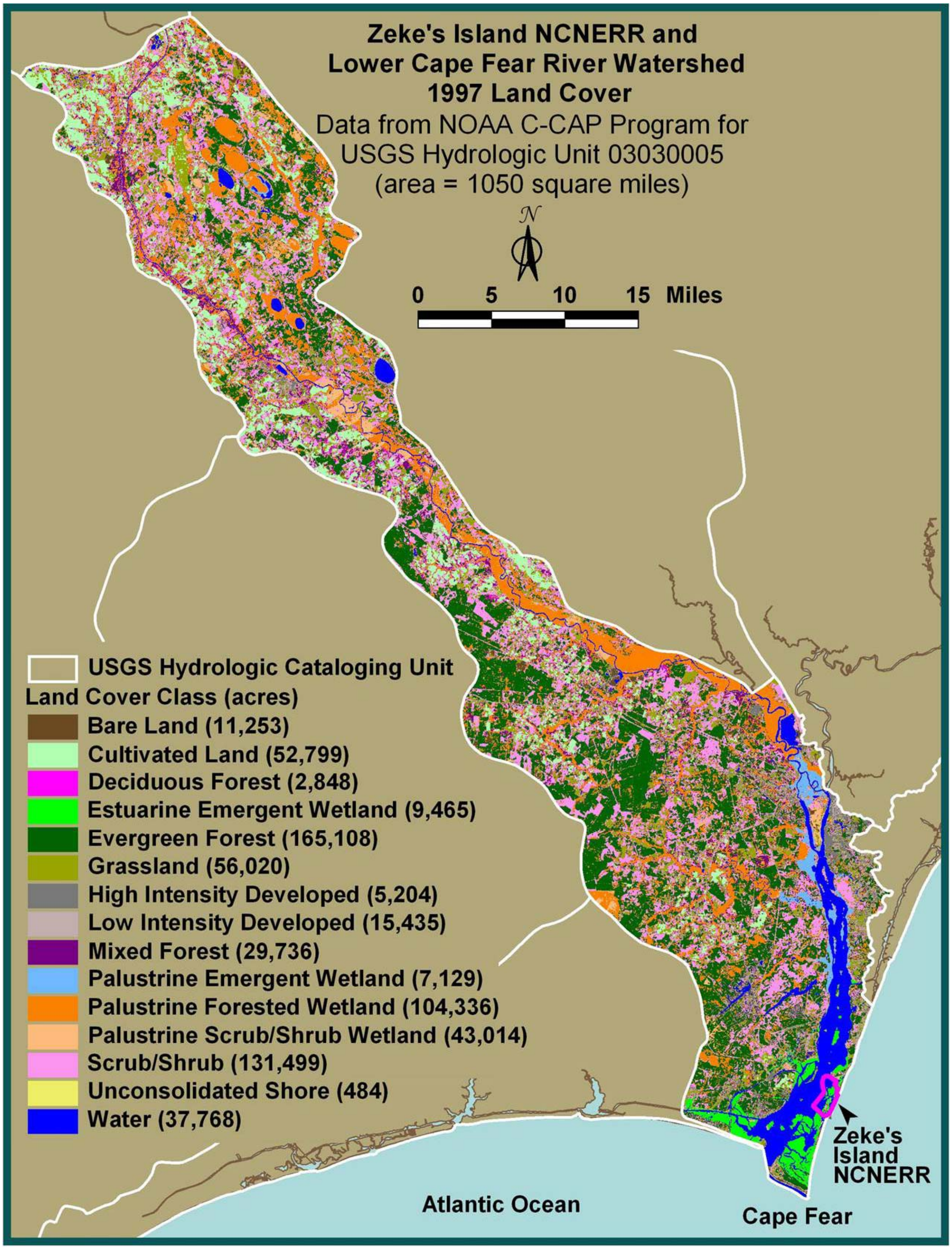


Figure 5.15b: Land use classification from 1997 in the Zeke's Island watershed.

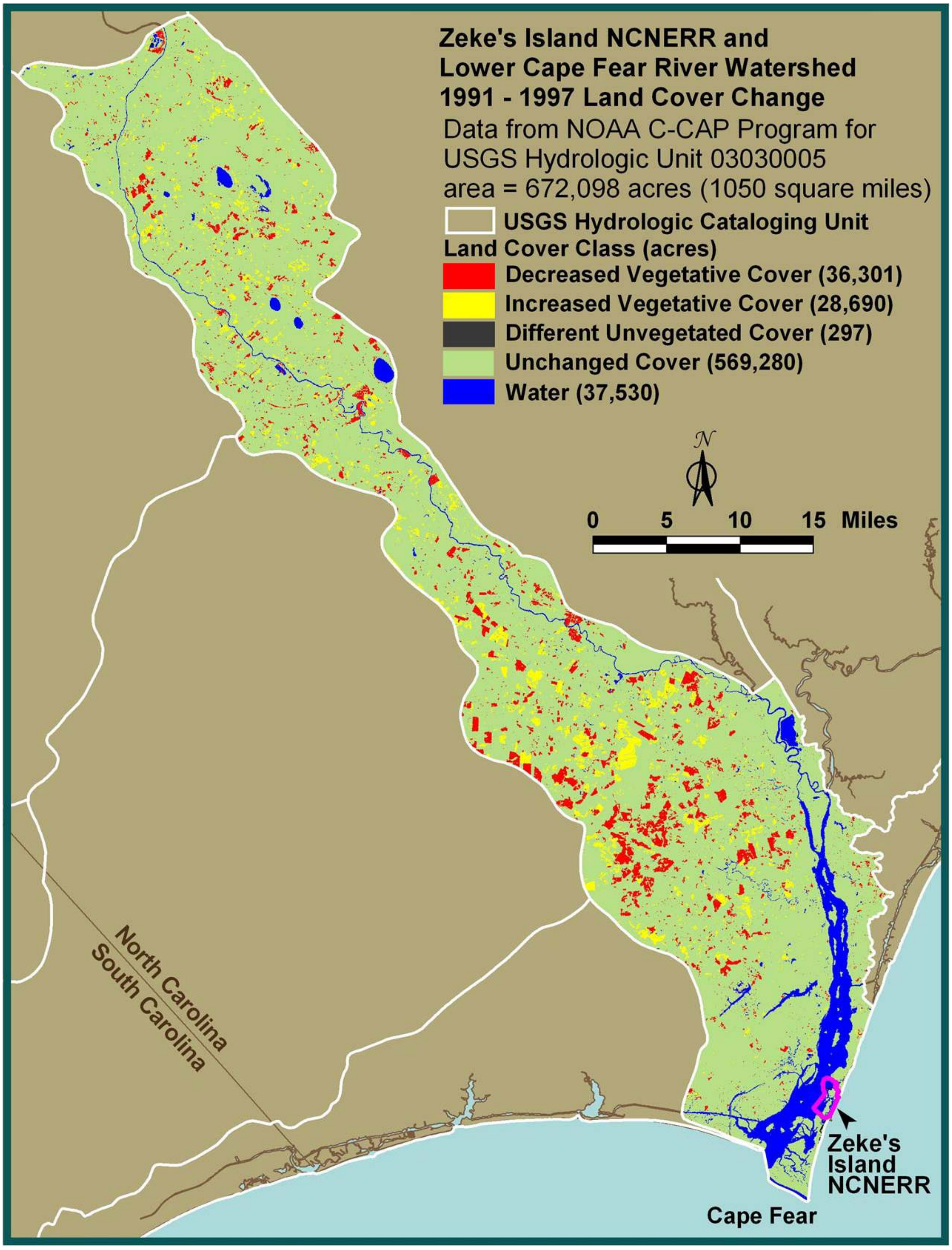


Figure 5.16: Changed land cover between 1991 and 1997 in the Zeke's Island watershed.

The loss of vegetation to Low and High Density Development between 1991 and 1997 for Zeke's watershed was 0.3%. This conversion mainly occurred in the southern extent of the watershed associated with development in the Wilmington region. It should be noted that the region has seen rapid development since 1997. Consequently, it is highly likely that the decrease in vegetative cover observed between 1991 and 1997 has only accelerated. Decreased vegetative cover has been unequivocally linked to declines in water quality (Mallin et al. 2000b; Mallin et al. 2001). Less vegetation leads to increased runoff and less filtering capacity within the watershed. Although this trend has not shown up in the water quality data yet (see Section 5.5), as the vegetation loss continues in the Zeke's Island watershed, water quality within Zeke's Island may decrease.

C: Public Use

The Zeke's Island area is popular for fishing, kayak and boating activities, bird watchers and beachgoers. While one of the purposes of the NERRS program is that the public has access to the Reserve properties, not all public activities are harmless. The area of the Reserve managed by Fort Fisher State Recreation area is part of an approximately 4 mile (6.4 km) stretch of beach that allows off road vehicle use. This off road vehicle use can disrupt the dune community. Sea turtle and colonial bird nests can be destroyed and the beach area itself contaminated by leaking petroleums. Off road vehicle access to the beach is a controversial issue that managers at Fort Fisher are trying to deal with in a management plan update. Given the historical use of this area for off-road vehicle access, it is unlikely that all off-road vehicle use will be prohibited. Thus, this activity will continue to be a potential impact upon the Beach/Dune communities at Zeke's Island.

Boating activities within the Zeke's Island can also cause detrimental harm. Boat propellers can disrupt benthic communities, and boat wakes can increase shoreline erosion. Two cycle outboard engines also discharge large amounts of petroleum products into the water during operation. Given the hydrology at Zeke's Island, over time and with increased use, this could lead to hydrocarbon pollution. As the marine outboard industry continues its transition to four stroke technologies, this issue may become less of an issue in the future.

The Rocks at Zeke's Island are improperly used by people to access the Reserve for the purposes of fishing and walking. This is an extremely dangerous use given the condition of the jetty making up The Rocks. The concrete cap on the jetty is failing, and the top of the jetty in many areas is covered at high tide. Marine growth and the jagged rocks make the jetty extremely slippery (Figure 5.17). Many rescue operations have been required to assist visitors who are either stranded or injured on The Rocks. Assisting visitors with more appropriate Reserve access is a high priority issue for NCNERR. Plans to improve the boat ramp to Zeke's Basin are underway through a partnership involving all Federal Point management entities. This project will provide visitors improved boat, kayak, and fishing access to the Zeke's Island. This will hopefully decrease the use of the Rocks for Reserve access.

Figure 5.17: The Rocks at Zeke's Island.

5.11: Research Activities

The information in this section is in a rapid state of flux. Research projects are constantly being initiated, executed and completed. As a result, this section will rapidly become dated. Despite this complication, it is still beneficial to describe the current body of research in this manner. The past projects represent a large foundation which future projects can utilize as planning guides. The projects currently being worked on are designed to address current high priority coastal management issues. Thus, in addition to the actual research results, these projects will provide future interested parties with awareness into what the high priority issues were for the Reserve at this time. The needed research represents current knowledge gaps that need to be addressed. While future projects may address some of these, the underlying issues such as eutrophication and sea level rise will still be valid.

A: Research Facilities

There are no research facilities on Zeke's Island. The NCNERR office is located at the University of North Carolina at Wilmington's Center for Marine Science approximately 15 miles (24 km) from Zeke's Island. The Center for Marine Science office covers 1,450 square feet, and provides offices for research staff as well as other staff, a common area/workspace, a storage area/mud room, and a large laboratory. The Center for Marine Science also affords NCNERR access to conference rooms, a machine shop, and boat parking for three NCNERR vessels that are used to support research and stewardship activities at Zeke's Island. Research activities at Zeke's Island can also be supported by the North Carolina Aquarium at Fort Fisher. This facility is located directly adjacent to the Reserve, and has space that staff of NCNERR can access for both research and education activities.

B: Historical Research Activities

Similar to the Currituck Banks component, the body of research available for Zeke's Island is small compared to Masonboro and Rachel Carson. Many of these historic research projects have been highlighted throughout the earlier parts of this chapter. Many others are contained in Appendix 6, the bibliography of work conducted within NCNERR. Most of the research projects that have been conducted at Zeke's Island were focused on the benthic infauna community, nutrients and contaminants and fish. General results from these projects indicate the there are healthy populations of benthic infauna at Zeke's Island, overall nutrient and pollutant loads at current time are low and Zeke's Island is heavily utilized by many fish species. These projects provide a great foundation to support future work.

C: Current Research Projects

There are currently two active studies going on within Zeke's Island. Reserve staff is conducting an investigation into the fluxes of oxygen and nutrients from the sediments within the Basin. This study was started in September of 2005 and will continue seasonally until June 2008. Benthic chambers are placed on the sediments within the basin and oxygen and nutrient concentrations within the chambers are monitored through time. The chambers are deployed at two end-member locations within the Reserve. The first location is in the high sediment nitrogen area located in the northwestern corner of the Basin (Figure 5.5). The other is in a shallow area just to the left of the public boat ramp. Both opaque and translucent chambers are being utilized. The goals of this study are to quantify the amount of nutrients coming from the sediments within the Basin, determine the sediment oxygen demand of the sediments within the Basin, and to determine if there is a benthic autotrophic community in the Basin and if so how it impacts the above fluxes of oxygen and nutrients.

A study into the efficiency of Sea Oats (*Uniola paniculata*) seed production relative to nutrient and pollen limitation has also just started up. This study will determine if the Sea Oats at Zeke's Island are putting out a full seed set and if not, whether the decrease in seed production is a factor of nutrient limitation or pollen limitation. This study will provide valuable knowledge for beach renourishment and dune building projects. This is a high priority management issue for many U.S. East Coast Local and State governments.

One ongoing monitoring project is also occurring at Zeke's Island. Yearly surveys for the presence of Beach Vitex (*Vitex rotundifolia*) (see section 5.9) are being conducted by staff from Fort Fisher State Park. If large amounts of Vitex are found during the surveys, eradication efforts are initiated.

5.12: Future Research Needs

A study into the effects of breaching the rock wall needs to be conducted. The Basin area of Zeke's Island is filling in. Navigation within the Reserve is extremely difficult at low tide. Local fishermen as well have started complaining that since the last inlet closed in 1999, fishing within the Reserve has suffered. These stakeholders believe that putting some openings within the Rocks will alleviate these problems. A well designed study examining the hydrology and fish within the Reserve is needed to assess the changes that could be expected from breaching the rocks. This project would also provide partnership opportunity. The U.S. Army Corps of Engineers would be involved since the Rocks were originally an Army Corps project, and because of the ongoing dredging within the Cape Fear River shipping channel. The North Carolina Fort Fisher Aquarium would be an ideal partner given the location of their Fort Fisher facility and knowledge regarding area fauna. The North Carolina Department of Cultural Resources would also need to be involved since the Rocks are listed as a cultural heritage resource and are under their jurisdiction.

The fish survey conducted by Ross and Bichy (2002) needs to be repeated. The original survey was conducted during a time of open inlet activity at Zeke's Island. Given the anecdotal evidence from the local fishermen that the fishing at the Reserve has declined, this study is vitally needed. The North Carolina Division of Marine Fisheries would be an excellent partner for this study. They routinely conduct fish surveys within North Carolina waters. Since a baseline already exists, the new work would be much more meaningful.

Assessment of atmospheric deposition of nutrients and mercury is another critical need for Zeke's Island. Atmospheric sources can contribute upwards of 50% of the new nitrogen to coastal oceanic waters (Pearl and Fogel 1994), and is the one of the main sources of mercury delivery to the coastal ocean. North Carolina just recently updated its fish consumption advisory to include several Ocean dwelling fish. Because of this human health risk, quantifying this pollutant source is critical. The United States Department of Agriculture would be a prime partner to help with this project. They currently operate a network of atmospheric samplers to quantify these parameters. Getting Zeke's Island into this network would be ideal given its location relative to population centers and prevailing wind patterns.

Studies into the health of the saltmarsh at Zeke's Island is needed. If the water areas of the Reserve are filling in, the saltmarsh in the region may be expanding in response. This activity would represent a fundamental shift from estuarine subtidal habitat to estuarine intertidal saltmarsh habitat. This shift would have implications for both flora and fauna within the Reserve. A detailed study investigating the marsh productivity, accretion and erosion rate, and overall health needs to be conducted. At the same time, the habitat mapping effort needs to be repeated so any change in marsh habitat can be assessed.

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Appendix 1: NERRS Strategic Plan

strategic PLAN | 2005 - 2010

National Estuarine Research Reserve System

research stewardship education

The National Estuarine Research Reserve System is administered by NOAA's National Ocean Service, Office of Ocean and Coastal Resource Management, Estuarine Reserves Division. For more information, visit us online at **www.nerrs.noaa.gov** or contact us at: 1305 East West Highway N/ORM5, Silver Spring, Maryland 20910. Phone number: 301-713-3155

Project Manager: George Cathcart

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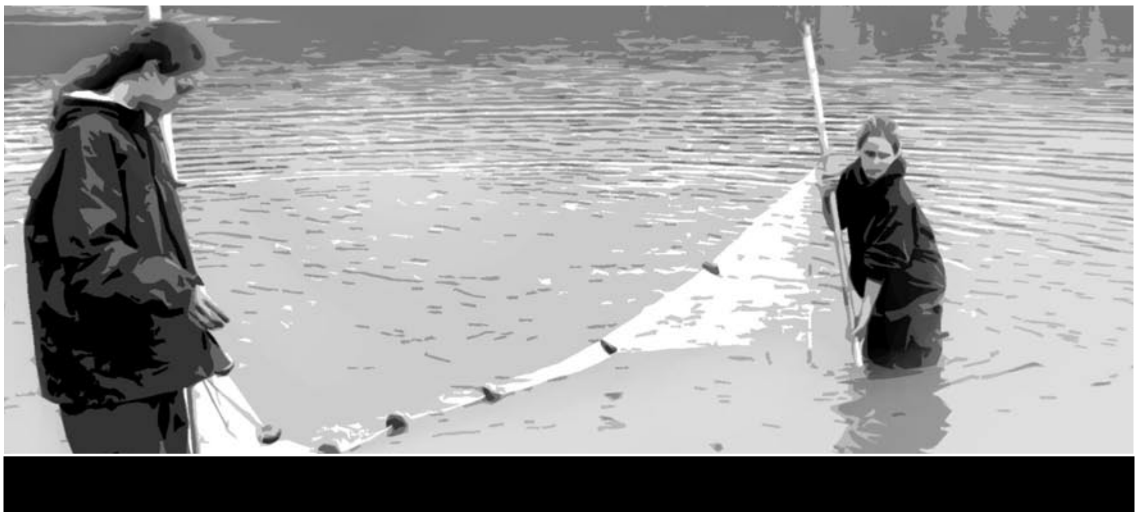
vision | Healthy estuaries and coastal watersheds where coastal communities and ecosystems thrive.



mission | To practice and promote coastal and estuarine stewardship through innovative research and education, using a system of protected areas.

goals

1. Strengthen the protection and management of representative estuarine ecosystems to advance estuarine conservation, research and education.

2. Increase the use of reserve science and sites to address priority coastal management issues.

3. Enhance peoples' ability and willingness to make informed decisions and take responsible actions that affect coastal communities and ecosystems.

Introduction

For thousands of years, coastal and estuarine environments have provided people with food, safe harbors, transportation access, flood control, and a place to play and relax. The pressures on the nation's coast are enormous and the impacts on economies and ecosystems are becoming increasingly evident. Severe storms, climate change, pollution, habitat alteration and rapid population growth threaten the ecological functions that have supported coastal communities throughout history. As a network of 27 protected areas established for long-term research, education and stewardship, the National Estuarine Research Reserve System (NERRS) has a unique role to play in keeping coastal ecosystems healthy and productive.

The reserve system is a partnership program between the National Oceanic and Atmospheric Administration and coastal states that has protected more than one million acres of coastal and estuarine habitat since the program was established by the Coastal Zone Management Act in 1972. NOAA provides funding, national guidance and technical assistance. Each reserve is managed on a daily basis by a lead state agency, non-profit organization or university with input from local partners. Through careful stewardship, innovative science and education, and relevant training programs, the reserves encourage careful management and protection of local estuarine and coastal resources.

The Coastal Zone Management Act created the reserve system to protect estuarine areas, provide educational opportunities, promote and conduct estuarine research and monitoring, and transfer relevant information to coastal managers. For the next five years, core reserve programs will focus on four priority topics: impacts of land use and population growth, habitat loss and alteration, water quality degradation, and changes in biological communities. The National Estuarine Research Reserve System's 2005-2010 Strategic Plan articulates how the strengths of the reserve system will be applied to address the major challenges of coastal management.

A Local Approach to National Priorities

Land use and population growth, water quality degradation, habitat loss and alteration, and changes in biological communities are not the only topics that reserves work on, but these four have risen to the top as deserving of adequate and strategic investment for the national system. These four topics are high priority science and training needs for coastal managers.[3] Reserve scientists, educators and land managers have identified these topics as locally and nationally important and appropriate to the mission of the National Estuarine Research Reserve System. Increased understanding about these topics will improve the reserve system's ability to protect and restore coastal watersheds and estuaries and empower individuals to make informed decisions. The nation's coasts and estuaries need to be managed, understood and appreciated at multiple scales. Through a network of locally oriented programs around the country, the reserve system provides insight into common information and management needs as well as data for use by local, regional and federal scientists and decision makers. Working at both the site level and as a national system, reserves have a greater impact than could be achieved through community efforts alone.

The goals, objectives and strategies outlined in this strategic plan will guide and support the National Estuarine Research Reserve System in its nation-wide efforts to improve coastal management, advance estuarine research, and educate current and future generations of coastal stewards.

Stewardship: *The responsible management of coastal resources using the best available information for the purpose of maintaining and restoring healthy, productive and resilient ecosystems.*

Priority Coastal Management Issues

1. Land Use and Population Growth

The United States' exploding coastal population results in competing demands for clean water, beaches, recreational and commercial space, infrastructure and housing. In 2003, an estimated 153 million people lived in coastal counties, which is approximately 53% of the total US population. Pressure to develop land in coastal areas is escalating at more than twice the rate of population growth. Land use changes can significantly impact coastal and estuarine species and habitat. The Pew Ocean Commission reports that when more than 10% of a watershed is covered in impervious surface such as roads, roofs and parking lots, aquatic resources begin to degrade.[1]

Coastal population and land use demands are not only increasing, they also are changing. Demographic and socio-economic trends show that the backgrounds and interests of people who are moving to the coast may be different from those of traditional fishing, commerce, or beach communities. The way people value and understand their relationship to the coast is reflected in the personal, political and professional choices they make. To make wise coastal resource management decisions, we need to understand the relationships among estuarine ecosystems and changing landscapes and attitudes. National Estuarine Research Reserves encourage the development and use of science based knowledge and tools in local land use planning, community development, and stewardship of public and private property.

2. Habitat Loss and Alteration

More than half of the nation's coastal wetlands have vanished since European settlement.[2] Estuarine and coastal environments continue to be altered and eliminated due to dredging, dams, recreational and commercial uses, flood and hazard mitigation, residential and infrastructure development, commercial port activities, and agriculture. Many of these activities disturb the physical, biological and chemical attributes of the estuary and therefore degrade the plants and animals that depend on the habitat to survive. Seagrass beds, marshes, shellfish, bird and fish populations can be affected by sedimentation, erosion, and hydrological, chemical or physical alteration of the habitat. Estuarine ecosystems also are vulnerable to coastal storms and sensitive to changes in climate and sea level. Coastal managers want to know more about how their choices influence coastal habitat and the species that live there. Better information will ensure that alternatives are considered for permitting, as well as planning and implementing successful restoration and mitigation efforts.[3]

Reserve research and monitoring programs increase the fundamental understanding of estuarine dynamics and add new information about the causes and consequences of changes in habitat quantity and quality. Research and stewardship programs at the NERRs also develop, implement and evaluate new techniques to restore and protect estuarine resources. Training programs and advisory services make this information available to professionals. Through education programs conducted at the reserves, students and citizens learn why these habitats are important and what they can do to keep them healthy.

3. Water Quality Degradation

Improving the condition of coastal water quality is a goal of the Coastal Zone Management Act and an ongoing struggle for all coastal regulatory agencies. Despite continuing local, state and federal investments, more than 20,000 beach closures were enforced in 2004[4] and more than 60% of estuarine waters were classified by the EPA as having degraded water in 2005.[5] Excess nutrients and chemical and biological contamination can cause human health problems and threaten aquatic life.

The Reserve System has been collecting water quality data for ten years to quantify short term variability and long term changes in estuarine waters. Through monitoring and studying changes in water quality, the reserves investigate how human activity, weather patterns, and estuarine characteristics contribute to changes in water quality that affect ecological processes and, consequently, human health. Reserves apply the knowledge generated through research and monitoring to improve water quality through habitat protection, restoration, and training and outreach programs.

4. Changes in Biological Communities

Biological communities are changing as a result of invasive species, over-harvest, climate changes, pollution, and habitat destruction. Invasive species out-compete or consume native organisms; habitat alteration and destruction displace some species and create opportunities for others; and changes in parameters such as temperature and salinity can shift the distribution of plants and animals. Chemical contamination and nutrient enrichment damage habitat and can alter the structure of floral and faunal communities. Over-harvesting biological resources also can change community structure and threaten valuable species. These problems impact natural interactions and linkages and lead to cascading indirect effects throughout the ecosystems.

Reserve research, stewardship, education, and training programs focus on understanding how changes in biological communities affect the way estuaries function. To minimize the negative impact of these changes, reserves investigate and communicate how to balance public needs with the protection of increasingly susceptible natural resources.

Guiding Principles

- Strong partnerships between NOAA, state agencies and universities, and other local partners are critical to the success of the reserve system.
- The reserve system integrates science, education and stewardship on relevant topics to maximize the benefits to coastal management.
- Reserves serve as a catalyst and a focal point for demonstrating and facilitating objective problem solving and best management practices.
- Reserves engage local communities and citizens to improve stewardship of coastal areas.
- Reserves implement an ecosystem-based management approach.

Goal One:

Strengthen the protection and management of representative estuarine ecosystems to advance estuarine conservation, research and education.

Objectives:

1. Biogeographically and typologically representative estuarine ecosystems are protected through the designation of new reserves.

2. Biological, chemical, physical, and community conditions of reserves are characterized and monitored to describe reference conditions and to quantify change.

3. Reserve ecosystems are conserved through land acquisition, natural resource management and restoration.

Strategies:

- Identify and designate new reserves consistent with system-wide policy and available resources.

- Collect system-wide measurements of the short-term variability and long-term changes in the water quality, biotic communities and diversity, land-use and land cover characteristics of estuarine ecosystems to support effective coastal zone management.

- Collect baseline information about the biological, physical, chemical, and socio-economic parameters of reserve biological and human communities.

- Integrate NERRS monitoring, data management, education and training capabilities in regional ocean observing systems.

- Implement land acquisition plans to enhance the long term integrity and diversity of reserve habitats.

- Restore and actively manage reserves' natural resources to meet local habitat and human use goals.

- Work collaboratively with other programs to evaluate and apply advanced technologies and tools to support effective coastal management.

- Provide facilities and support to manage the natural resources within reserve boundaries.

Goal Two:

Increase the use of reserve science and sites to address priority coastal management issues.

Objectives:

1. Scientists conduct estuarine research at reserves that is relevant to coastal management needs.
2. Scientists have access to NERRS datasets, science products and results.
3. The scientific community uses data, tools and techniques generated at the NERRS.

Strategies:

- Understand coastal decision maker science and training needs through needs assessments, coastal management science needs surveys, etc.
- Work collaboratively with other programs to conduct research on priority management issues in the reserves.
- Offer Graduate Research Fellowships to master's and doctoral students to conduct science that is relevant to coastal management and to train students in estuarine science.
- Deliver monitoring and observation data to the scientific community.
- Disseminate reserve science through publications, outreach and technology transfer.
- Generate time-series data and empirical studies to describe the ecological condition of reserve habitats.
- Promote reserve science products through web sites, communication materials, and other avenues to meet the needs of diverse stakeholders.
- Increase visibility and reinforce the credibility of NERRS science through communication efforts about NERRS research and monitoring.
- Attract scientists and practitioners to use reserves as reference sites.
- Conduct and facilitate relevant research in reserve watersheds.
- Synthesize reserve data into information for use in decision making.
- Conduct and facilitate research into education effectiveness and behavior change.
- Ensure that reserves have facilities and research support to meet the needs of visiting scientists and staff.

Scientist: *A person who uses principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses.*

Goal Three:

Enhance people's ability and willingness to make informed decisions and take responsible actions that affect coastal communities and ecosystems.

Objectives:

1. People are aware of the ecological, economic, historical, and cultural importance of estuarine resources.

2. People understand how human choices and natural disturbances impact social, economic, and estuarine ecological systems.

3. People apply science-based information when making decisions that could impact coastal and estuarine resources.

Strategies:

- Provide educational opportunities that increase students' understanding of estuarine science and technology.

- Implement and participate in public programs and events to raise awareness and understanding about estuaries and the NERRS.

- Produce and distribute educational materials and web-based products that raise public awareness about estuaries, the NERRS, and NERRS education products.

- Train teachers to educate students about coastal watersheds and estuaries.

- Deliver monitoring and observing data to diverse user groups in a useful format.

- Improve the willingness and ability of communities to restore and protect coastal ecosystems.

- Provide science-based information and training to individuals and organizations.

- Assist restoration practitioners in developing and applying effective restoration techniques.

- Implement volunteer programs to engage local citizens in advancing the goals of the reserves.

- Conduct programs to encourage people to make personal choices that reduce their impact on coastal resources.

- Evaluate programs to determine how people apply information and knowledge.

- Build and maintain educational facilities and interpretive displays.

Sources

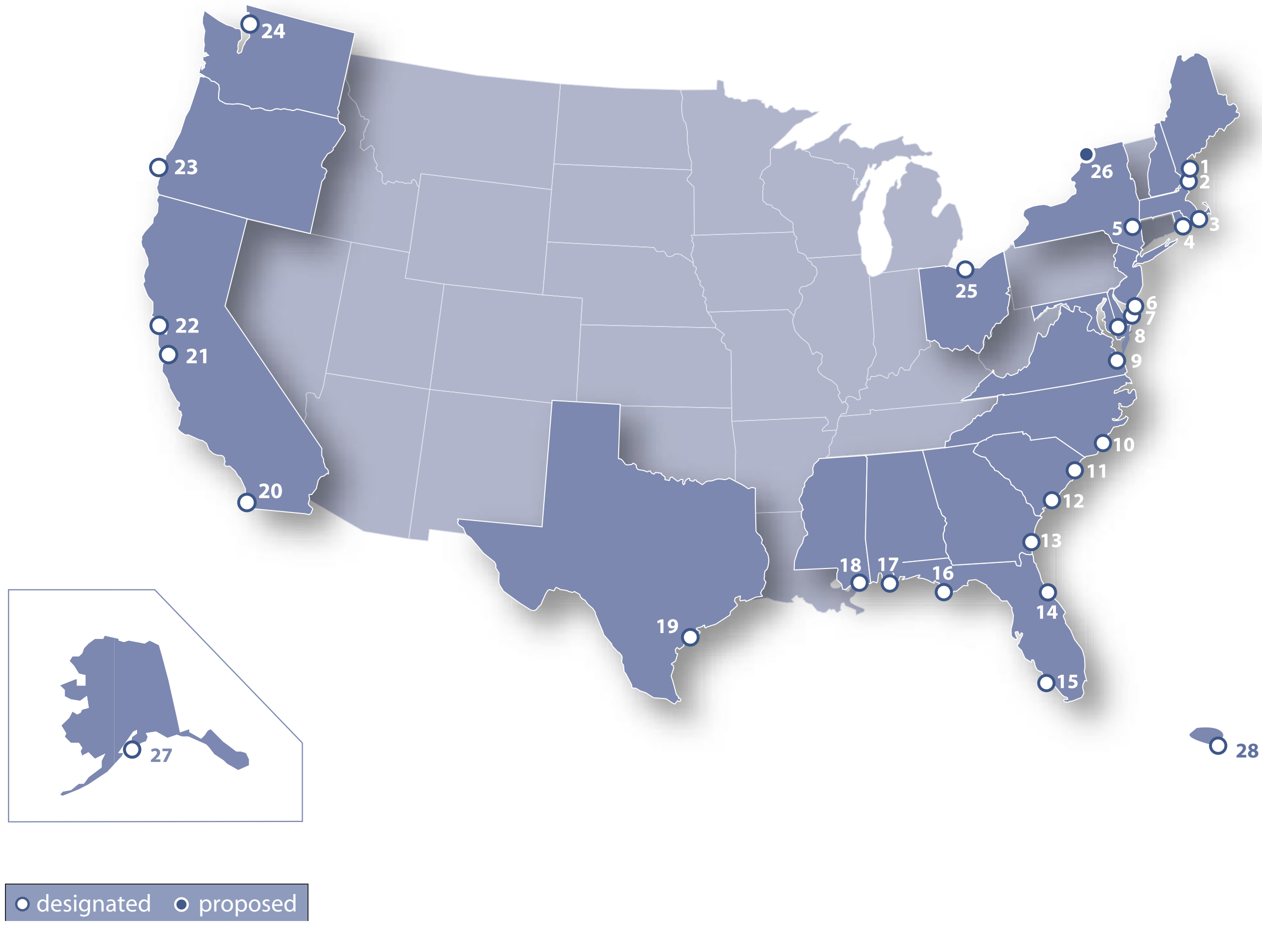
[1] Pew Ocean Commission Report

[2] United States Commission on Ocean Policy Report

[3] NERRS Coastal Training Program Trends Analysis Report, Improving Links Between Science and Coastal Management

[4] National Resource Council website

[5] EPA Coastal Conditions Report

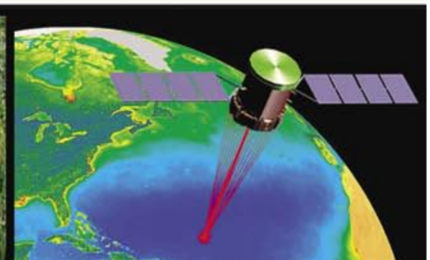


1. Wells Reserve, Maine
2. Great Bay Reserve, New Hampshire
3. Waquoit Bay Reserve, Massachusetts
4. Narragansett Bay Reserve, Rhode Island
5. Hudson River Reserve, New York
6. Jacques Cousteau Reserve, New Jersey
7. Delaware Reserve
8. Chesapeake Bay Reserve, Maryland
9. Chesapeake Bay Reserve, Virginia
10. North Carolina Reserve
11. North Inlet-Winyah Bay Reserve, South Carolina
12. ACE Basin Reserve, South Carolina
13. Sapelo Island, Georgia
14. Guana Tolomato Matanzas Reserve, Florida
15. Rookery Bay Reserve, Florida
16. Apalachicola Reserve, Florida
17. Weeks Bay Reserve, Alabama
18. Grand Bay Reserve, Mississippi
19. Mission-Aransas, Texas
20. Tijuana River Reserve, California
21. Elkhorn Slough Reserve, California
22. San Francisco Bay, California
23. South Slough Reserve, Oregon
24. Padilla Bay Reserve, Washington
25. Old Woman Creek, Ohio
26. Proposed Reserve—St. Lawrence River
27. Kachemak Bay Reserve, Alaska
28. Jobos Bay Reserve, Puerto Rico

Appendix 2: NERRS Research and Monitoring Plan

National Estuarine Research Reserve System

Research and Monitoring Plan (2006-2011)



The National Estuarine Research Reserve System is administered by NOAA's National Ocean Service, Office of Ocean and Coastal Resource Management, Estuarine Reserves Division. For more information, please contact Susan White, Research Coordinator, NOAA Estuarine Reserves Division, at Susan.White@noaa.gov. Or, visit **http://www.nerrs.noaa.gov**.

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Executive Summary

This document: 1) describes the current status of research and monitoring efforts within the National Estuarine Research Reserve System (NERRS), 2) describes five research priority areas that the system will focus on over the next five years, and 3) outlines a set of strategies that will enable the system to move forward in conducting and supporting research to address specific coastal management needs as well as improve our basic understanding of estuarine systems.

The five priority research areas were identified with input from a variety of sources including reserve research staff and managers, the NERRS Strategic Plan, and national documents outlining national coastal research needs and priorities. NERRS priority research areas focus on:

- Habitat and Ecosystem Coastal Processes
- Anthropogenic Influences on Estuaries
- Habitat Conservation and Restoration
- Species Management
- Social Science and Economics

Key reserve research goals, objectives, and strategies presented in this research plan will assist the reserve system in addressing the five research priority areas, as well as meeting strategic goals outlined by the system, in the following five years. Social science and economics are disciplines that could engender relevant research related to the priority areas listed. The research goals outlined for this plan include:

Goal 1: Biological, chemical, physical, and ecological conditions of reserves are characterized and monitored to describe reference conditions and to quantify change.

Goal 2: Scientists conduct research at reserves that is relevant to coastal management needs and increases basic understanding of estuarine processes.

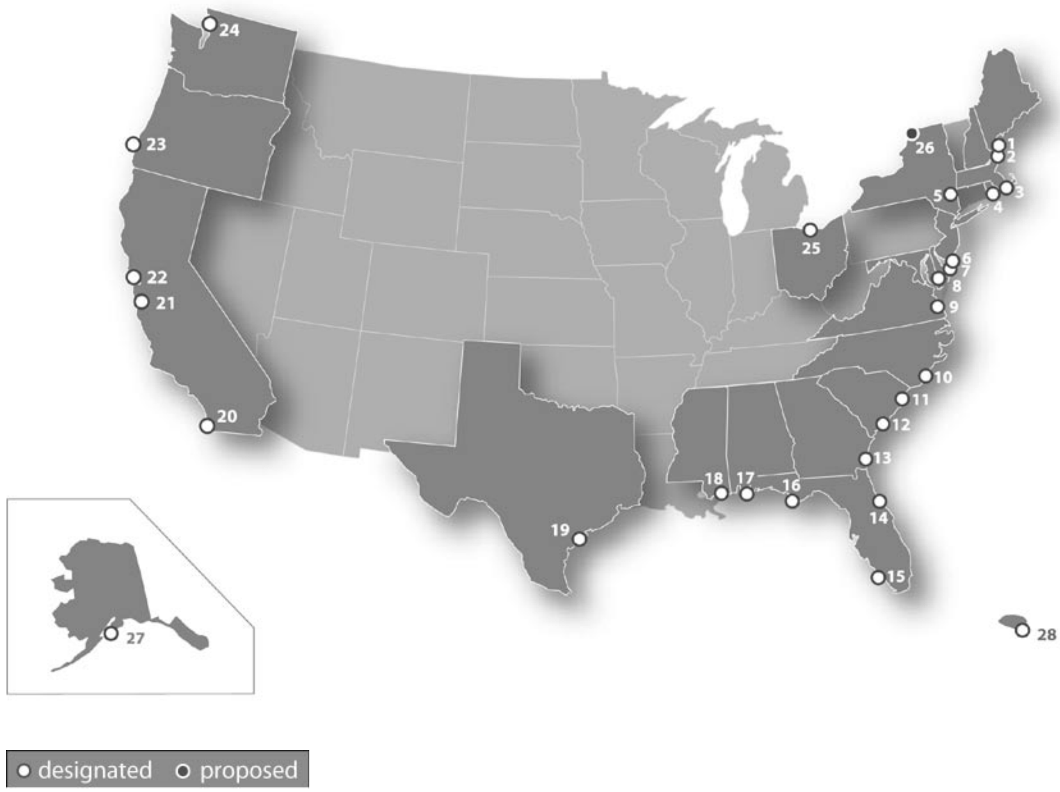
Goal 3: Scientists, educators, and coastal managers have access to NERRS datasets, science products and results.

Goal 4: The scientific, coastal management and education communities, as well as the general public, use data, products, tools, and techniques generated at the NERRS.

The NERRS has developed this research and monitoring plan to guide national, regional, and local research efforts that promote the protection and conservation of estuarine habitats through the provision of improved ecological information.

NATIONAL ESTUARINE RESEARCH RESERVES

A network of 27 protected areas



1. Wells Reserve, Maine
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12. ACE Basin Reserve, South Carolina
13. Sapelo Island, Georgia
14. Guana Tolomato Matanzas Reserve, Florida
15. Rookery Bay Reserve, Florida
16. Apalachicola Reserve, Florida
17. Weeks Bay Reserve, Alabama
18. Grand Bay Reserve, Mississippi
19. Mission-Aransas, Texas
20. Tijuana River Reserve, California
21. Elkhorn Slough Reserve, California
22. San Francisco Bay, California
23. South Slough Reserve, Oregon
24. Padilla Bay Reserve, Washington
25. Old Woman Creek, Ohio
26. Proposed Reserve—St. Lawrence River
27. Kachemak Bay Reserve, Alaska
28. Jobos Bay Reserve, Puerto Rico

Introduction

The National Estuarine Research Reserve System (NERRS) is a network of 27 reserves dedicated for long-term research, monitoring, education and resource stewardship. These 27 estuaries and coastal watersheds, representing different biogeographic regions of the United States, were established by the Coastal Zone Management Act of 1972. The reserve system operates as a partnership program between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states and territories. NOAA provides funding, national guidance and technical assistance, while the states provide matching funds, personnel, and managerial oversight. Each reserve is managed on a daily basis by a lead state agency or university, with input from local partners. This partnership program between NOAA and the coastal states and territories protects more than 1.3 million acres of estuarine land and water, which provide essential habitat for wildlife; offer educational opportunities for students, teachers and the public; and serve as living laboratories for scientists.

One of the Guiding Principles of the Estuarine Reserves Division (ERD), as outlined by the NERRS Strategic Plan (2005-2010), is to "demonstrate and facilitate the development of sound science and best practices for improved local and regional coastal resource management." The reserve system is also mandated to provide protection of estuarine and coastal natural resources and to promote research and education activities that lead to greater protection of these systems. To facilitate the development of sound science for improved coastal decision making and the protection of natural resources, the reserve system has developed a research and monitoring plan that focuses on integrating the long term research goals of NOAA with those of the reserve system on local, regional, and national scales. As a system, the NERRS will approach research and monitoring from the perspective of an ecosystem approach to management which includes accounting for ecosystem knowledge and uncertainty, engaging in a collaborative and incremental approach to achieving research goals, employing adaptive techniques to improve research efforts, and balancing diverse environmental and societal objectives to inform coastal management decisions.

The purpose of this research plan is to help set priorities, provide a focus for partnership development, and help allocate financial resources and time to high priority issues. In addition, it will inform coastal resource managers and governmental, non-governmental, and academic scientists of the reserve system's research priorities and capabilities. This will serve to both enhance research collaborations and leverage resources to further the state of coastal research science to support improved coastal management. The research plan will also support reserve research, education, and stewardship staff in their efforts to seek

The National Estuarine Reserve System Research Plan

Audiences	Results
Scientists (governmental, non-governmental, and academic)	Communicates reserve research priorities Guides collaborative projects
Coastal resource managers	Leverages research resources within NOAA and external to the reserves

National Estuarine Research Reserve System

Vision: Healthy estuaries and coastal watersheds where human and ecological communities thrive.

Mission: To practice and promote coastal and estuarine stewardship through innovative research and education, using a system of protected areas.

external funding for reserve programs related to coastal resource management. As a living document, this five-year reserve research plan provides a basis for refining research priorities and strategies and also allows for the flexibility that is required to support a national research effort that is implemented primarily at local to regional scales. While this iteration of the plan focuses on natural science research, it is anticipated that this plan will be expanded to include research plans that address reserve needs in social science, restoration science, and education research within five years. Refining and aligning national, regional and local research priorities is challenging, yet efforts to do so will continually improve the relevance and impact of NERRS research efforts. While this research plan guides system-wide priorities, individual reserves will also pursue research and monitoring projects that address questions unique to their sites or regions. Reserve management plans will guide individual site-based research and monitoring priorities.

Background

The National Estuarine Research Reserves were established to provide opportunities for long-term research, education, and stewardship. According to 15 CFR Part 921 National Estuarine Research Reserve System Program Regulations, Subpart A, § 921.1 mission, goals and general provisions, three goals stand out as supporting the development of a coordinated research plan for the NERR system.

- Ensure a stable environment for research through long-term protection of NERR resources,
- Address coastal management issues identified as significant through coordinated estuarine research within the System, and
- Conduct and coordinate estuarine research within the System, gathering and making available information necessary for improved understanding and management of estuarine areas.

The authority to develop a system-wide research plan within the NERRS also resides in Title 16, Chapter 33, §1461 National Estuarine Research Reserve System, of the Coastal Zone Management Act (CZMA). Within the CZMA, specific research guidelines address the need for a plan for coordinated research and the development of related performance measures. Specifically, these guidelines suggest:

- Developing a mechanism for identifying, and establishing priorities among, the coastal management issues that should be addressed through coordinated research within the System,
- Establishing common research principles and objectives to guide the development of research programs within the System, and
- Establishing performance standards upon which the effectiveness of the research efforts and the value of reserves within the System in addressing the coastal management issues identified may be measured.

NOAA has recently redesigned its approach to research to follow a more interdisciplinary, cross-cutting strategy to address defined priority research areas (NOAA, 5-yr Research Plan, 2005). The new infrastructure for NOAA's research focuses on four mission goals: Ecosystem, Climate, Weather and Water, and Commerce and Transportation Goals. The reserve system is a strong contributing member of the Coastal and Marine Resources Program within the Ecosystems Goal Team. The reserve system also contributes indirectly to the Climate Goal as well as the Weather and Water Goal. The mission of the Ecosystems Goal is to protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management. Through the integrative and collaborative efforts of reserve research, education, and training activities, coastal ecosystems will be better understood and coastal decision making will improve.

National Oceanic and Atmospheric Administration	
Vision:	Societally relevant research that forms the scientific basis for more productive and harmonious relationships between humans and their environment.
Mission:	To conduct research, develop products, provide scientific understanding and leadershipand to conduct outreach towards fostering NOAA's evolving environmental and economic mission.

NOAA's Ecosystem Goal Team Selected Outcomes

- **Healthy and productive coastal and marine ecosystems that benefit society.**
- **A well informed public that acts as stewards of coastal and marine ecosystems.**

Existing NERRS Research and Monitoring Programs

NERRS System-Wide Monitoring Program

The NERRS System-Wide Monitoring Program (SWMP; pronounced "swamp") was developed in 1995 to provide researchers, resource managers, educators, and other coastal decision makers quantitative measures with which to assess short-term variability and long-term change in estuarine conditions. At present, the program is moving into its second decade of collecting critical estuarine water quality and meterological data. A key feature in establishing SWMP was the implementation of a set of consistent standard operating procedures that ensure the long-term collection of data that is comparable across time and locations. As such, SWMP is able to provide robust data for such things as, for example, trend analysis and change detection of anthropogenic impact assessments, as well as the effects of large-scale forcing (e.g., El Niño/Southern Oscillation and North Atlantic Oscillation, climatic conditions, sea level rise, and global climate change) and localized, stochastic events (e.g., hurricanes and contaminant spills) on estuarine conditions within a reserve. By implementing these standard operating procedures in a coordinated fashion across all 27 reserves, SWMP data can also be used for meaningful comparisons of estuarine conditions at the regional and national levels, thus enhancing the value of the reserves as a system of national reference sites. Thus, SWMP provides valuable short- and long-term data to researchers, natural resource program managers, coastal educators, and other coastal decision-makers.

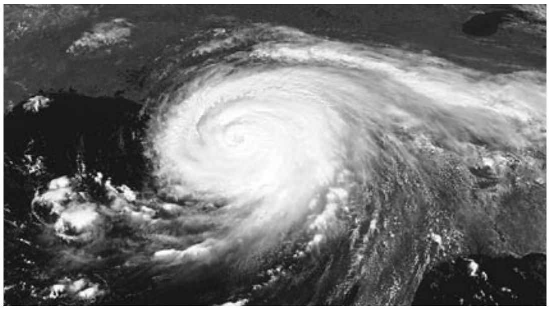


Photo Credit: NOAA's National Environmental Satellite, Data, and Information Service (NESDIS)

The NERRS System-wide Monitoring Program (SWMP) is able to provide both long-term data for trend analysis and change detection as well as data on the impact of localized, stochastic events such as Hurricane Katrina (2005) on estuarine conditions within reserves.

The NERRS and NOAA established SWMP as a phased monitoring approach that focuses on three different ecosystem characteristics:

Abiotic Factors, including: atmospheric conditions, water quality (nutrients, contaminants, etc.) and physical parameters (salinity, tidal range, groundwater, freshwater inflow, bathymetry, etc.);

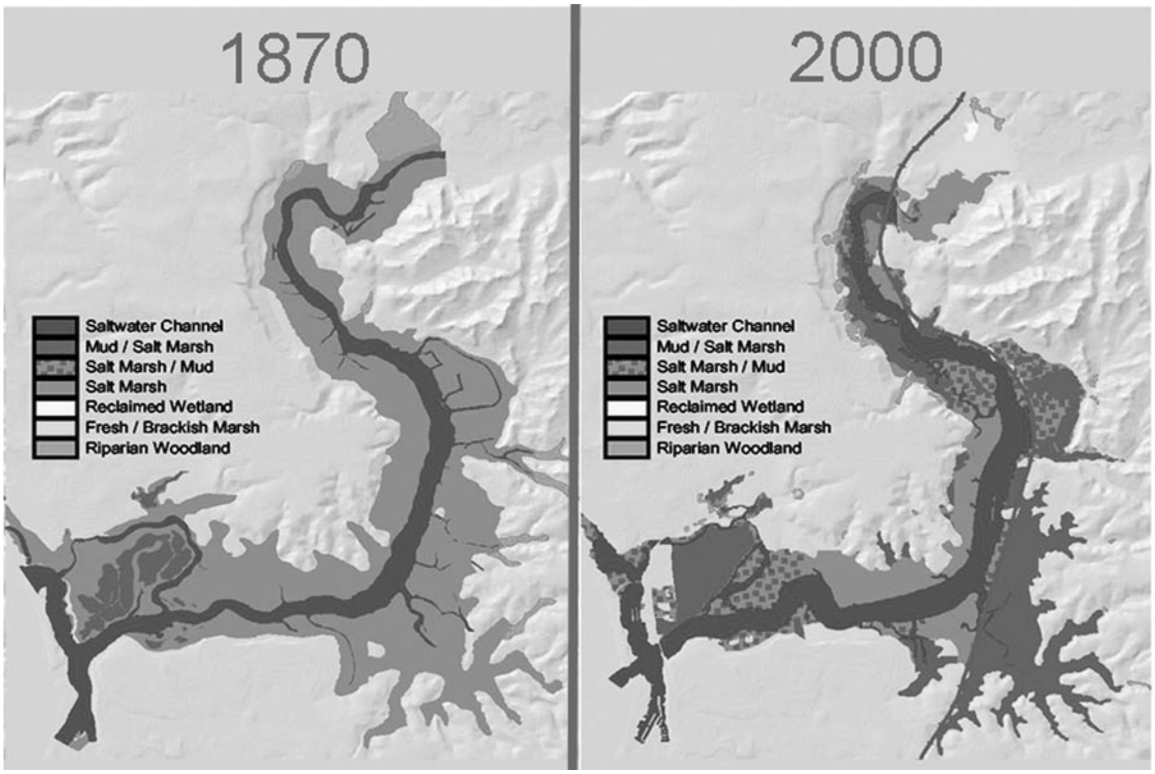
Biological Monitoring, including: biodiversity, habitat and population characteristics;

Watershed and Land Use Classifications, including: changes in consumptive and non-consumptive uses.

Phase 1 of SWMP focuses on monitoring a suite of water quality and meterological parameters over a range of spatial (local, regional, national) and temporal (minutes, hours, days, months, years) scales. Data loggers are continuously deployed at a minimum of at least four water quality stations at each reserve to record measurements of conductivity, salinity, temperature, pH, dissolved oxygen, turbidity, and water level at thirty minute intervals. Each reserve also collects monthly measurements of water column nutrients (e.g. nitrate, nitrite, ammonia, and ortho-phosphate) and chlorophyll-a concentrations at the four stations. In addition, diel sampling (2.5 hour sampling intervals over 25 hours) for nutrients and chlorophyll-a occurs at a minimum of one site each month. At least one weather station at each reserve records meteorological measurements of local temperature, wind speed and direction, relative humidity, barometric pressure, rainfall, and Photosynthetic Active Radiation at 15- to 30-minute intervals. Reserve staff have laid the technical groundwork necessary for the phase-one SWMP data collection network to be integrated into the backbone of the United States' Integrated Ocean Observing System (IOOS), with a near-real-time telemetry system for timely dissemination (NOAA 2004).

Photo Credit: Rookery Bay National Estuarine Research Reserve

Conservative estimates for the volume of data collected by the NERRS abiotic sampling program are: 13.5 million data points for water quality, 34.4 million data points for meteorological monitoring, and 31,104 data points for nutrient monitoring.



Wetland change analysis within the Elkhorn Slough, CA NERR utilizing habitat mapping techniques to quantify a 50% loss in marsh vegetation in the past 150 years (Van Dyke and Wasson 2005).

Phase 2 of SWMP focuses on characterizing biotic diversity in reserve estuarine ecosystems by assessing community composition and species abundance and distributions. Reserve projects will explore patterns of inter-annual variability and spatial distribution of estuarine communities, including emergent and submerged vegetation, invasive species, benthic, plankton and nekton communities, as well as targeted monitoring for the occurrence and distribution of invasive species. Since 2004, biomonitoring demonstration projects at 16 reserves have focused on developing baseline information on submerged and emergent vegetation distribution for use in future land use change research, determining changes in the health and distribution of these communities with long-term changes in water quality and quantity, and quantifying changes in estuarine habitat types. Rigorous protocols were established to ensure a national strategy for implementing this biomonitoring initiative, while retaining local flexibility as appropriate for individual reserves (Moore and Bulthius 2003). There are currently plans for a special journal edition focusing on local, regional, and national application of this biological monitoring information.

Phase 3 of SWMP is well-aligned with phase 2, as both of these efforts utilize remote sensing imagery and ground truthing. The central objective focuses on tracking and evaluating changes over time in coastal and estuarine habitat and land use in the watershed. Reserve staff have developed a common classification system to provide the system with consistent, and thus nationally comparable, habitat and watershed mapping efforts (Kutcher et. al. 2005). The use of a common classification system will enable the NERRS to assess habitat change at local, regional, and national scales and identify the status of coastal habitats (i.e., degrading, improving, or maintaining). In addition, system-wide use of this classification system will provide a baseline of information that can be applied to management and restoration activities and guide conservation and protection of these important habitats. Currently, five reserves have piloted this classification system and the protocol was refined in the fall of 2005. It is anticipated that this classification system will be adopted by the reserves in 2006. Phases 2 and 3 will be implemented as resources become available.

Further details regarding parameters measured, data acquisition, data dissemination, deployment protocols, developing phases of SWMP, and applications of NERRS SWMP data within research, coastal decision making and education communities are available in the NERRS SWMP Plan (NOAA, 2002; Appendix A) and the NERRS SWMP 10th Anniversary Report (Owen and White, 2005). To ensure the collection of accurate, high quality SWMP data, the reserve system established a Centralized Data Management Office (CDMO; http://cdmo.baruch.sc.edu) in 1995. Quality assurance/quality control protocols have been established for the collection of all monitoring parameters and for the metadata (FGDC content compliant) associated with the time-series datasets.

A number of publications use and synthesize SWMP data. A recent special issue of the Journal of Coastal Research highlights a number of reserve research efforts (Kennish and Finkle 2004), and past syntheses have produced additional information regarding patterns within the reserve system (Wenner et. al., 1998 and 2000).

NERRS Graduate Research Fellowships

The NERRS Graduate Research Fellowship (GRF) program provides master's degree students and Ph.D. candidates with an opportunity to conduct research of local and national significance focusing on enhancing coastal zone management. Since its inception in 1997, the program has funded more than 160 fellows from 56 universities across the country. The five research focus areas for the GRF program are: eutrophication, effects of non-point source pollution and/or nutrient dynamics; habitat conservation and/or restoration; biodiversity and/or the effects of invasive species; mechanisms for sustaining resources within estuarine ecosystems; and economic, sociological, and/or anthropological research applicable to estuarine ecosystem management (Figure 1).

Reserve Site-Specific Research

The National Estuarine Research Reserves serve as living laboratories for on-site staff, visiting scientists and graduate students. Since its inception, a primary goal of the program has been to ensure a stable environment for research through long-term protection of reserve resources and ecosystems. Reserve management plans include site-based research

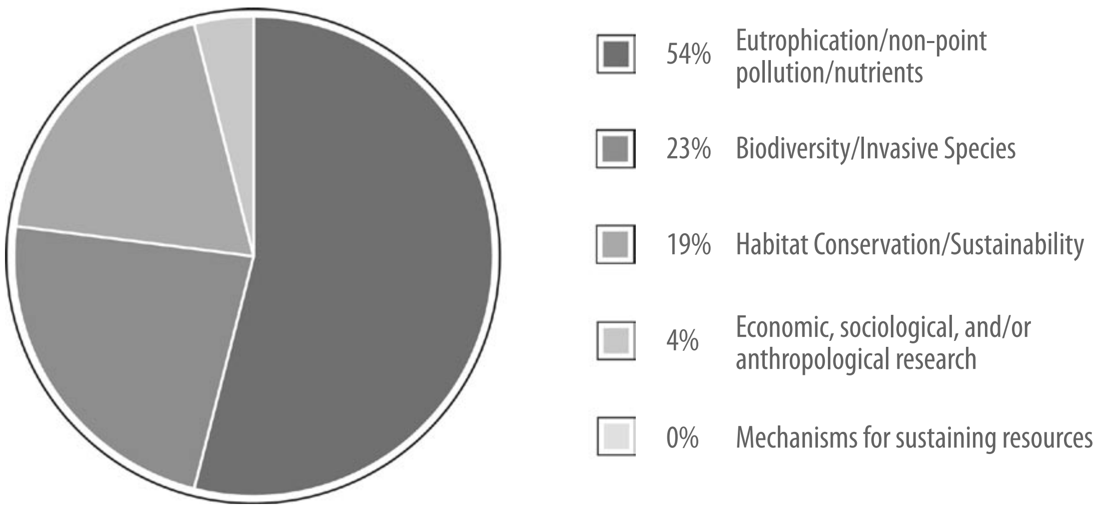


Figure 1. *Snapshot of NERR Graduate Research Fellowship research project focus areas for 2005.*

and monitoring priorities. Research activities within the reserve system occur in a number of ways. Each reserve has a research coordinator who is primarily responsible for coordinating research and monitoring efforts that occur within the reserve. As a group, the research coordinators' scientific expertise encompasses a wide range of subjects including nutrient biogeochemistry, population, community and ecosystem ecology, and physical oceanography. The breadth of knowledge and expertise that is shared among research coordinators constantly improves and pushes the reserve system toward new and successful research opportunities focused on improving coastal management decisions at individual reserves and nationally. In addition, scientists from a variety of backgrounds (e.g. academic, non-governmental, state and federal governments) conduct research within each reserve in coordination with reserve research staff. This also broadens the scientific knowledge base for the NERRS.

Research and Monitoring Partnerships

Additional research and monitoring efforts within the reserves are supported by a series of partnerships within NOAA and other programs. Examples of these partnerships include:

- The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) is supported through a partnership between NOAA and the University of New Hampshire (http://www.ciceet.unh.edu). Research projects funded by CICEET occur within reserve boundaries or the adjacent watershed and focus on a variety of environmental issues from habitat restoration research to developing and piloting new technologies to monitor water quality and contaminants.

- NOAA's Chesapeake Bay Office (NCBO) and the NERRS support specific research and monitoring programs that focus on understanding and restoring Chesapeake Bay communities.

- NOAA's Coastal Services Center (CSC) has supported remote sensing and geographical information system (GIS) tools, training, and development programs within the reserve system.

- NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) has partnered with reserve sites to demonstrate the effectiveness of collaboration to produce an improved, more effective product that will be used by coastal managers and others for improved decision making. CO-OPS National Water Level Observation Network (NWLON) is expanding to include reserve sites in an effort to link SWMP data with more detailed tide, water level, and weather information within the Reserve.

- NOAA's National Weather Service (NWS) and National Environmental Satellite, Information, and Data Service (NESDIS) have partnered with the NERRS to deliver newly telemetered, real-time, SWMP weather and water data through NOAA's Geostationary Operational Environmental Satellites (GOES) and the NWS's Hydrometerological Automated Data System (HADS) to the NERRS Centralized Data Management Office.

- NOAA's Sea Grant Programs, Coastal Zone Management Programs, and National Marine Sanctuary Programs support research projects that address priority research needs within or adjacent to reserve sites.

- The National Atmospheric Deposition Program (NADP)/National Trends Network (NTN) and United States Geological Survey (USGS) have established atmospheric deposition monitoring programs within and close to reserve boundaries.

- The Environmental Protection Agency's National Estuary Program (NEP) and the NERRS collaborate at local scales to accomplish research that is relevant for both programs and at national scales to improve science information exchange bewteen programs.

- The Smithsonian's Environmental Research Center (SERC) and the NERRS have ongoing collaborations that focus on monitoring and forecasting expansion and distribution of invasive species within the reserve system.

- NOAA's National Centers for Coastal Ocean Science (NCCOS) collaborates with the reserve system to investigate long-term trends in eutrophication and contaminants in estuarine systems across the nation. The reserves continue to be involved in NCCOS's national estuarine eutrophication assessments and the Mussel Watch Program.

- NOAA's Educational Partnership Program (EPP) established the Environmental Cooperative Science Center (ECSC) in October 2000 with Florida A&M University in collaboration with Delaware State University, Jackson State University, Morgan State University, South Carolina State University, and the University of Miami Rosenstiel School. The ECSC addresses ecological and management issues through studies and collaboration with several NERR sites and the Florida Keys National Marine Sanctuary. The ECSC NERR partners include: Apalachicola, FL NERR; Grand Bay, MS NERR; ACE Basin, SC NERR; Delaware NERR; and Chesapeake Bay, MD NERR.

- The National Science Foundation's coastal Long-term Ecological Research (LTER) sites offer the NERRS additional research and collaborative opportunities. Sapelo Island NERR is located within the Georgia Coastal Ecosystems LTER site.

Research Plan Framework and Development

The research plan for the NERRS has been developed to address topic areas and technological needs identified at national, regional, and local levels. Considerable challenges must be overcome to develop a coherent national research plan for the reserve system that can simultaneously incorporate and accommodate the flexibility in approaches and design that are necessary to meet local and regional coastal research and management needs, while also addressing nationally significant coastal issues. Scaling research priorities up from a local and regional perspective to address nationally relevant coastal issues requires the reserves to constantly evaluate how individual reserve research can support broader national estuarine information and application needs.

Development of this plan has been coordinated by NOAA's Estuarine Reserves Division with primary input from the individual reserves and NOAA's Office of Coastal Resource Management. Reserve research coordinators and managers contributed directly to the formulation of this plan by identifying the primary research needs and coastal management issues within reserve sites (Appendix B). The plan incorporates information contained in several documents produced by the reserve system including the NERRS Strategic Plan for 2005-2010 (Appendix C), the NERR System-Wide Monitoring Plan, NERR management plans, site profile documents (Appendix D), and local needs assessments conducted by the NERR Coastal Training Programs. Additional research needs and coastal management issues were identified through the findings of several recent compilations including: (a) the CICEET survey of coastal management needs for new and improved technology (2004); (b) the Coastal States Organization (CSO) census of national and regional priorities to improve links between science and coastal management needs (2004); (c) the CSO survey of state coastal observational and monitoring needs (2004); (d) research needs for coastal resource management identified by the Estuarine Research Federation (ERF, 2005); (e) the National Research Council priorities for coastal ecosystem science (1994); (f) the PEW Ocean Commission Report; and (g) findings from the U.S. Commission on Ocean Policy (2004). As an example of the range of coastal management priorities identified, Table 1 presents CSO's results for both national research needs and needs identified by NERRS Manager's as well as key estuarine threats identified by the PEW Ocean Commission. Information provided by these sources has been used to identify a series of reserve research priorities that are both nationally relevant and tailored to meet the regional and site specific needs of individual reserve sites.

Table 1. *Coastal management research needs and threats identified from surveys conducted by the Coastal States Organization and PEW Ocean Commission.*

The Coastal States Organization top ranked research needs:

Top National Level Research Needs	Top NERR Research Priorities
Cumulative Effects	Cumulative impact assessment
Source identification and tracking	Ecosystem indicators
Trends/change analysis	Source identification and tracking
Remote Sensing	Improved models
Improved Models	Rapid detection and monitoring of invasive species
	Risk and vulnerability assessments
	Restoration prioritization
	Ecological characterizations

The PEW Ocean Commission identified the following key estuarine threats and pressures:

Coastal development
Nutrient runoff into coastal rivers and bays
Unsustainable fishing activities impacting nearshore/estuarine systems
Invasive species introductions
Global climate change impacts

The framework for the NERR Research Plan provides a pathway for integration and support of site-based research projects to meet local, regional, and national coastal and estuarine management needs (Figure 2). Science investigations and research projects undertaken at individual NERR sites are supported by state, NOAA, and other sources, and are typically conducted by NERR scientists, graduate students, visiting investigators, contractors, and volunteers to meet the needs identified by local and regional coastal resource managers. Taken collectively, the research effort undertaken within the network of NERR sites contributes in a "bottom-up" manner to the goals and objectives of the NERR Research Plan. Conversely, the NERR Research Plan serves a "top-down" role to provide guidance, coordination, and the national context to support site-based research within the NERRS network. Financial support for the site-based research activities is typically derived from the states, federal agencies, regional programs, non-governmental organizations, and/or other sources depending on the topic and focus of the research problem. As the focal point for coordination of NERRS science activities, the NERR Research Plan serves as an integral element of the NERR Strategic Plan for 2005-2010. The NERR Strategic Plan functions to coordinate the research and monitoring activities with other elements of the NERRS (e.g., education/outreach, coastal training, resource stewardship, and management). This in turn serves to facilitate investigations undertaken by multiple reserves, and to leverage support for NERRS research internally in cooperation with other NOAA science programs and externally in partnership with outside groups. Science activities completed under the guidance of the NERR Strategic Plan and NERR Research Plan contribute to the objectives of the NOAA-wide Research Plan (2005), and they address the cross-cutting issues identified by the Ecosystem Goal for Coastal and Marine Resources. Collective integration of NERRS science at many levels (e.g., NERRS sites, NERR Research Plan, NERR Strategic Plan, NOAA Research Plan) will help meet a sub-set of the national priorities for coastal and estuarine ecosystem science.

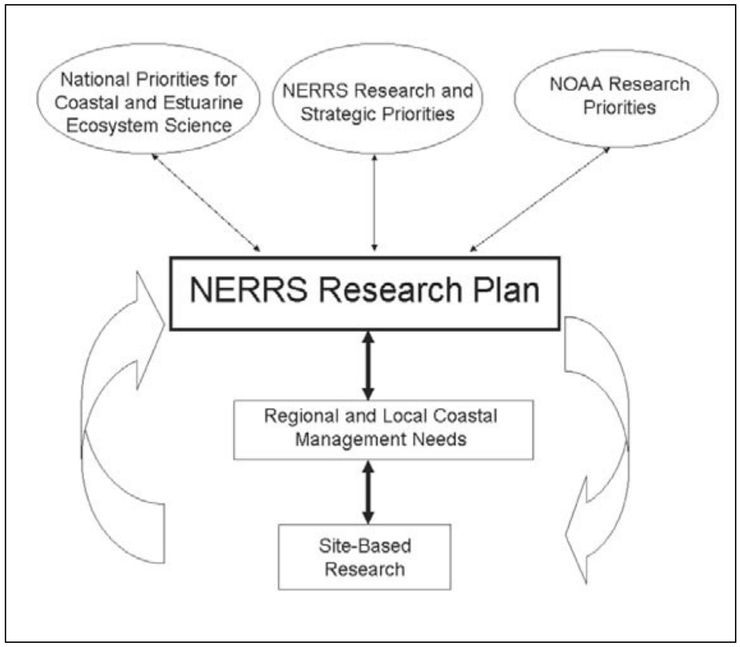


Figure 2. *The development components and anticipated science contributions associated with the NERRS Research and Monitoring Plan at local, regional, and national scales.*

research activities undertaken within the reserve system. The NERR Research Plan nests within the broader, NOAA 5-Year Research Plan, while simultaneously addressing the regional and local needs of the reserves.

Priority Coastal Management and Research Issues

The U.S. Commission on Ocean Policy recommended that NOAA adopt an ecosystem-based approach to the development of coastal and ocean policy that is based on the best available science for marine and estuarine ecosystems. NOAA's focus on protecting, restoring, and managing the use of coastal and ocean resources through an ecosystem approach is closely aligned with the specific

The highest priority U.S. coastal management issues identified at both the national and regional levels focus on assessments of impacts due to changing shoreline and watershed land use and coastal habitat change (Table 1). It is clear that nationally and regionally, coastal managers are concerned about increased development pressures in coastal and estuarine areas, and are supportive of research and monitoring efforts that will address the growing need for information to document impacts on the coastal environment. Environmental contamination, habitat degradation, eutrophication, invasive species, declines in fish species, freshwater diversions, sea level changes, and sediment problems are significant stressors to coastal and estuarine ecosystems. Consequently, it is not surprising that the top-ranked research needs for coastal managers are: (a) new approaches to address the cumulative effects of multiple environmental stressors, and (b) source identification and tracking for coastal environmental pollutants. Priority information needs identified by the U.S. coastal management community include quantitative data to describe temporal trends and changes in land use, coastal habitats, and habitat quality, and the priority needs for new technology focus on development of useful products from remote sensing imagery and improved conceptual and numerical models to predict the consequences of stressors on environmental change.

The priority research needs identified by the estuarine research community (e.g., academia, agencies, NGOs, and private-sector scientists; ERF, 2005) are highly complementary to those identified by the U.S. coastal management community. The highest priority research needs are: (a) investigations of anthropogenic impacts on estuarine ecosystem functions; (b) documentation of linkages among coastal land use activities and estuarine habitats; (c) increased understanding of environmental variability, sensitivity, and resilience; and (d) new infrastructure to link estuarine science, management, and policy (ERF, 2005). These priority estuarine research issues are consistent with the priorities for coastal ecosystem science identified by the National Research Council (i.e., integrated monitoring of coastal habitats; watershed hydrology and ecosystem processes; water quality and aquatic ecosystem functions; ecological restoration and rehabilitation; development of observational and predictive systems). In combination, the priority research needs identified by the U.S. coastal management and research communities clearly articulate a suite of pressing science-management issues that can be addressed by the network of representative reserve sites and the NERRS Research Plan. For example, within individual reserves, program priorities are broadly focused on research regarding habitat change/land use, cumulative impact assessments, tracking of pollutants, development of indicators that link land use with ecosystem impacts, estuarine ecosystem functions, invasive species, land use change analysis, the success of restoration efforts, habitat use by fish and shellfish, integrated monitoring, and improved models that predict and/or simulate changing environmental conditions.

National Estuarine Research Reserve System Research Plan

The NERRS Strategic Plan outlines four priority coastal management issues; land use and population growth, habitat loss and alteration, water quality degradation, and changes in biological communities. The five main NERRS research priority areas clearly address these identified estuarine threats and the supporting research questions, goals and strategies described below will enable the NERRS to better understand estuarine processes, provide scientific data that can be applied and thus improve coastal management decisions and the protection of estuarine habitats (Figure 3).

The five main NERR research priority areas were identified as a result of information complied from within the NERRS, NOAA and external sources as outlined previously. NERR research priority areas include:

- Habitat and Ecosystem Coastal Processes
- Anthropogenic Influences on Estuaries
- Habitat Conservation and Restoration
- Species Management
- Social Science and Economics

Research projects that are designed to tackle NERRS research priority areas will clearly address the four priority coastal management issues identified within the NERRS Strategic Plan and thus support improved coastal decision making and a greater understanding of estuarine systems. The research categories are interrelated on one or more levels. In addition, research can include natural or social science research. For example, social science and economic research can be used as a tool to address natural science issues. In the true ecological sense, this is a web of research topics with threads leading from topic to topic. NERRS- specific research questions are focused on coastal management issues related to these five priority areas.

Key Questions for each priority area might include:

Habitat and Ecosystem Coastal Processes

- What are the natural scales of variability in coastal and estuarine ecosystem processes?
- How do short-term climatic events (e.g., tropical storms and hurricanes), and large-scale events (e.g., El Nino, North Atlantic Oscillation, global climate change) impact estuarine water quality parameters and estuarine habitats?
- How do variable watershed inputs and oceanic physical forcing drive changes in estuarine ecosystems (including nutrient cycling, sediment transport, larval transport, etc.)?

Anthropogenic Influences on Estuaries

- How do human activities impact estuarine water quality, living resources (e.g.,

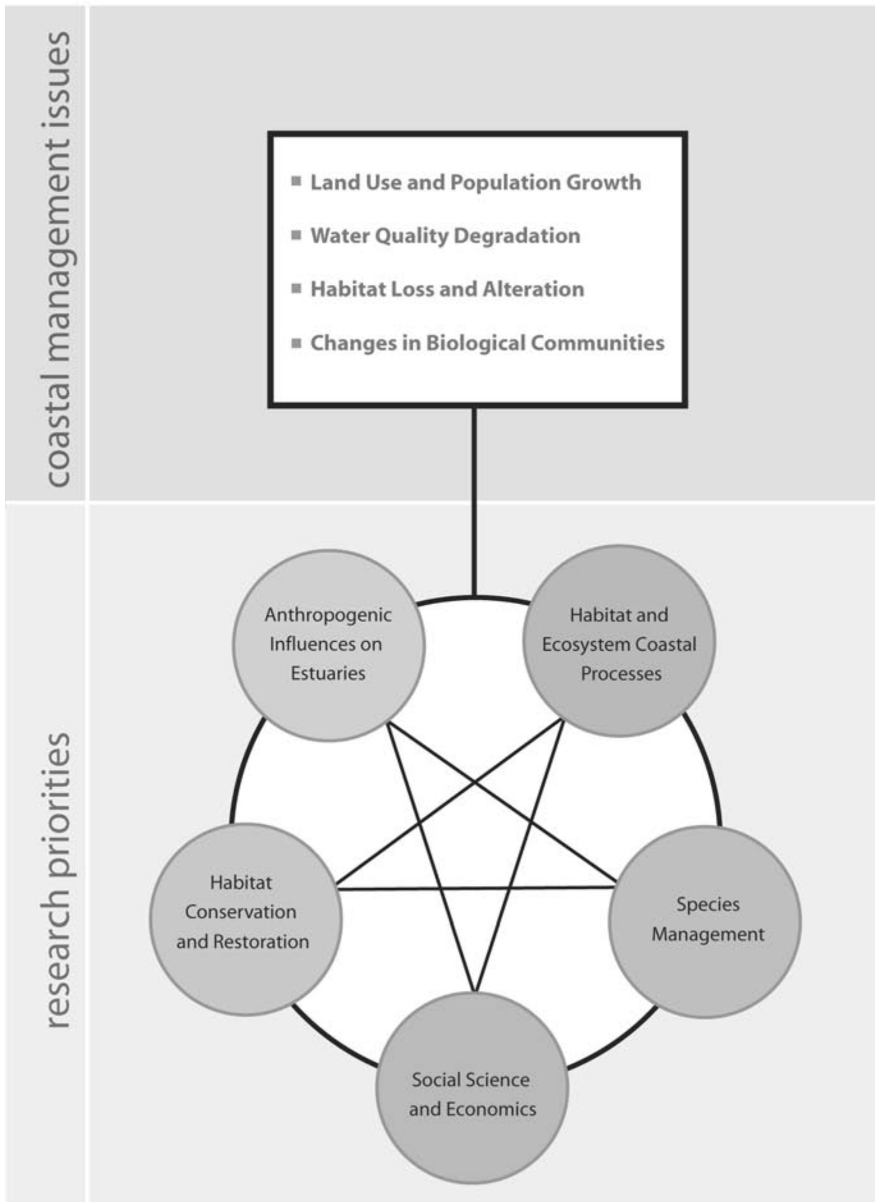


Figure 3. *The 5 NERRS Research Priorities, anthropogenic influences on estuaries, habitat and ecosystem coastal processes, habitat conservation and restoration, species management and social science and economics address key coastal management issues.*

submerged aquatic vegetation, benthic communities, habitat fragmentation), and ecosystem function (or "services")?

- Are current watershed and coastal nutrient management measures effective in minimizing impact to estuarine ecosystems and resources?

- What is the magnitude and impact of atmospheric deposition on estuaries?

Habitat Conservation and Restoration

- What impacts does climate change have on habitat integrity and restoration success?

- How does the restoration of tidal hydrology impact estuarine communities (e.g. colonization of invasive species, resiliency of native species, etc.).

- What are the linkages between adjacent upland habitats and tidal wetlands and how critical are those links to the recovery of wetland function?

- What invasive species control methods are effective?

- How can reserves serve as reference sites for restoration efforts?

Species Management

- How do invasive species affect native species and communities?

- What tools can be developed and used to detect invasive species, respond rapidly and appropriately to these events, and monitor for additional impacts?

- Can natural variations in the distribution and density of organisms be distinguished from human impacts on these populations?

- How do estuarine and coastal communities and individual species populations change under varying environmental conditions?

- How are estuarine species and communities affected by landscape or watershed scale changes (e.g., habitat proximity, subtidal-intertidal linkages, connectivity)?

Social Science and Economics

- How are coastal populations demographics changing and how does this/will this impact natural resource protection and management?

- What are the economic tradeoffs/effects of increasing development and urbanization in the coastal zone on traditional commercial enterprises such as seafood harvesting, etc.?

- How do human perceptions of health risks influence coastal decision making and natural resource protection?

- What are the cumulative impacts of multiple human recreational and economic activities on the coastal environment?

Implementation Strategy

Research Goals

The reserve research and monitoring plan includes a number of priority goals for the system (a few of which are outlined below) to support national and regional efforts toward improving the protection of coastal and estuarine natural resources by conducting research that supports sound coastal decision making. These goals are not meant to be an exhaustive list as by definition this research plan is designed to be supportive of regional and local research initiatives that address reserve system and NOAA research needs. The goals listed below provide a basic foundation on which reserve science efforts can build. It is fully anticipated that these strategies will be modified appropriately over time as the Reserve system continually assesses the quality and impact of research results and products in order to continue to improve and sustain coastal environments (Appendix E). The desired ecosystem approach to management is an iterative process, where results from previous actions and research are used to refine and improve future efforts in research and management decisions. Implementation of some strategies depends on the availability of sufficient resources.

Research Goal 1: Biological, chemical, physical, and ecological conditions of reserves are characterized and monitored to describe reference conditions and to quantify change.

Objectives:

1. Water and weather parameters, biodiversity, and habitats located within the reserve and nearby watershed areas are sufficiently characterized, both spatially and temporally, to support trend analysis efforts.

2. Biological monitoring data collected by the reserve system are incorporated into an accessible database for use.

3. Biological monitoring efforts within the NERRS are synthesized regularly as appropriate at national, regional and local scales.

Strategies:

- Complete site profiles.

- Continue system-wide measurements of the short-term variability and long-term changes in estuarine water quality and meteorological parameters, consider expanding suite of standard water quality parameters tracked (e.g. addition of chlorophyll a to fixed station sampling) as possible.

- Collect system-wide measurements of the short-term variability and long-term changes in submerged aquatic vegetation and emergent vegetation.

- Collect additional appropriate biological monitoring information on important habitats, species, and ecological functioning within reserves.

- Link system-wide measurements of chemical and physical parameters with biological monitoring information.
- Implement a system-wide habitat classification system that allows for site specific and system-wide analysis.
- Synthesize biological monitoring pilot project data and revise protocol to reflect lessons learned and move toward system-wide operational status.
- Develop a system-wide remote-sensing strategy that supports and enhances ongoing biological monitoring and habitat classification efforts.
- Partner with appropriate university, state agency, federal agency, local government and private entities to bring monitoring of sediment quality, benthic communities, nekton populations and shoreline change into reserves.
- Integrate NERRS monitoring data into the national IOOS program.

Research Goal 2: Scientists conduct estuarine research at reserves that is relevant to coastal management needs and increases basic understanding of estuarine processes.

Objectives:

1. Research efforts focus on understanding the response of estuarine and coastal processes to specific natural and anthropogenic impacts.
2. Research efforts focus on estuarine habitat and species management and the restoration of critical ecosystem function.
3. Research efforts incorporate an ecosystem-based approach to management that involves multiple stakeholders.
4. Scientists from multiple agencies (ie. academic, governmental, NGO's, etc.) utilize reserves as a platform for research.

Strategies:

- Attract CICEET, GRF, and external researchers to reserves to work on priority research topics: habitat and ecosystem coastal processes, anthropogenic influences on estuaries, habitat conservation and restoration, species management, and social science and economics.
- Revisit GRF priority research areas to update them as appropriate to reflect NERRS coastal management needs.
- Utilize SWMP data to drive hypothesis driven research within reserves and adjoining watersheds.

- Support ecosystem-based approaches to coastal research and management projects that incorporate adaptive management strategies to improve research efforts and applications.
- Design and regularly update a database that archives and tracks research projects within the NERRS that are supported by non-Section 315 NERRS funding (i.e. other NOAA monies, academic, NGO, external funding sources, etc.) and address priority coastal management and estuarine research needs.
- Improve current partnerships and explore new opportunities to leverage resources that support reserve priority research efforts.
- Facilitate research efforts between and across NERRS, both regionally and nationally, to address important coastal issues.
- Design a regional or national assessment of the NERRS that integrate research results from the reserves to determine if NERRS environmental conditions are improving or declining and why (i.e. a "report card" for the NERRS).

Research Goal 3: Scientists, educators, and coastal managers have access to NERRS datasets, science products and results.

Objectives:

1. Scientists are aware of available NERRS datasets and research products.
2. Biological monitoring data is available for academic scientists, coastal managers, and educators to use.
3. Data visualization products are available.

Strategies:

- Develop a useful and informative database for accessing past and current research projects, data, and resulting publications and products.
- Establish a data management strategy and database to support biological monitoring and land use/habitat information.
- Disseminate science through publications, outreach and technology transfer.
- Develop and implement appropriate communication tools to increase awareness of science conducted, data application, and data availability within the NERRS.
- Assess CDMO capabilities and needs in relation to expanding NERRS research and monitoring, data accessibility, and data visualization efforts.

Research Goal 4: The scientific, coastal management and education communities, as well as the general public, use data, products, tools, and techniques generated at the NERRS.

Objectives:

1. Researchers and coastal managers identify priority resource needs that will improve research activities at the local, regional, and national scales.
2. Enhance the use of NERRS scientific data in coastal training, stewardship, and education programs within the NERRS.

3. The NERRS are increasingly recognized as a primary source of information about estuaries and coastal areas.

Strategies:

- Re-evaluate priority research needs biennially.
- Revise and update SWMP Plan based on NERRS research and monitoring needs.
- Conduct a SWMP External Review.
- Coordinate with education and outreach professionals early in the formation of research activities, where feasible, to target educational product development and dissemination from research activities.
- Provide science based information and training to individuals and organizations that make decisions about coastal resources on a regular basis in a professional or volunteer capacity.
- Improve the ability of restoration practitioners to restore and protect coastal ecosystems.
- Provide science based information to assist in the production and dissemination of educational materials and web based products that use science generated at the reserve.
- Provide science based information and training to citizens so that they can make informed decisions about protecting coastal resources through their own actions.

Appendices:

A. NERRS SWMP Plan Executive Summary

B. Regional NERRS research priority issues

C. NERRS Strategic Plan (2005-2010)

D. NERRS Site Profile Status

E. Key milestones anticipated for achieving NERRS research goals

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Appendices

Appendix A: **NERRS System wide Monitoring Program Plan Executive Summary**

THE NATIONAL ESTUARINE RESEARCH RESERVE'S SYSTEM-WIDE MONITORING PROGRAM (SWMP): A SCIENTIFIC FRAMEWORK AND PLAN FOR DETECTION OF SHORT-TERM VARIABILITY AND LONG-TERM CHANGE IN ESTUARIES AND COASTAL HABITATS OF THE UNITED STATES

(Updated Spring 2006)

Executive Summary

Estuaries are among the most dynamic and productive environments known. They are transitional places where salt and fresh water mix and serve as nursery areas for numerous commercial fish and shellfish species. These habitats also act as rest stops for migratory birds, filters for pollution and buffers against coastal erosion. The high value that society places on estuaries for living, working and recreation has made these habitats among the most densely populated in the United States.

An increased awareness of estuarine degradation resulted in the passage of legislation aimed at protecting estuarine ecosystems. A landmark piece of legislation enacted by Congress was the Coastal Zone Management Act (CZMA) of 1972, which was the beginning of what became the National Estuarine Research Reserve System (NERRS). Currently, 27 reserves in 22 states and territories protect over 1.3 million acres of estuarine waters, wetlands and uplands. The NERRS was built on a foundation of partnerships among state and federal agencies and community groups. The reserves have a management framework in place that links stewardship, public education and scientific research and thus provide an ideal vehicle to establish a nationally coordinated monitoring program.

In 1992, the reserve system proposed the establishment of a coordinated monitoring program that would attempt to identify and track short term variability and long term changes in the integrity and biodiversity of representative estuarine ecosystems and coastal watersheds for the purposes of contributing to effective coastal management. The initial phase of the NERR System wide Monitoring Program, known by its acronym SWMP (pronounced "swamp"), began in 1995. The initial focus was on monitoring a suite of water quality and atmospheric variables over a range of spatial and temporal scales. Water quality parameters measured include pH, salinity, conductivity, temperature, dissolved oxygen, turbidity and nitrate, ammonia, ortho-phosphate, and chlorophyll a. Atmospheric parameters measured include temperature, wind speed and direction, relative humidity, barometric pressure, rainfall, and photosynthetic active radiation.

The purpose of the updated SWMP document is to lay out a revised scientific framework and plan for the NERR SWMP that will assist in guiding the program with the perspective gained over the past 10 years, for the next 10 years. It is not a static document, especially regarding costs and implementation details, but it portrays priority activities for ongoing and future SWMP efforts. This document describes a conceptual framework for NERR SWMP laying out the steps that will assist in addressing coastal management problems. Updates, including steps taken to expand abiotic monitoring within the reserves and initiate the second and third phases (e.g. biological monitoring and watershed and land use classifications) are included. In addition, the SWMP plan contains some general areas for future targeted monitoring including additional expansions of abiotic, biological and watershed/land use components (e.g., contaminant monitoring, monitoring of invasive species, conducting benthic/subtidal mapping, etc.).

The advantages of the NERRS monitoring program are that it:

- Provides an ecosystem-based network for understanding the temporal and spatial variability of ecosystem components and their interactions.
- Provides a long-term database for the estuarine reserves' protected area network.
- Establishes a baseline for measuring changes in environmental conditions and ecological processes.
- Provides a research framework for evaluating ecosystem conditions and interpreting and predicting responses to change.
- Provides the basis for an ecosystem-based approach to managing coastal resources.

The scientific value of NERR SWMP data increases over time because it is through the collection of long-term data that subtle changes in environmental conditions are identified. This established monitoring program continues to be an opportunity to increase our understanding of how various environmental factors influence estuarine processes by collecting high-quality, long-term data.

By understanding how estuaries function and change over time, we can begin to predict how these systems respond to changes in climate and human-induced perturbations. Research is critical to the interpretation of monitoring results and for testing hypotheses generated by monitoring.   Whereas monitoring determines whether and how much the environment has changed from its reference state, research helps establish causal relationships. The reserve system's monitoring program, coupled with NERR-supported research programs, provides a foundation for developing solutions to coastal management problems by answering how estuarine ecosystems change and why.

Appendix B. Regional NERRS Research Priority Issues

		REGIONS							
		NW Pacific	California	Caribbean	Northeast	Mid-Atlantic	Southeast Atlantic	Gulf of Mexico	Great Lakes
	Total Count (Rank Order)	Region Total (N = 3 sites)	Region Total (N = 3 sites)	Region Total (N = 1 site)	Region Total (N = 5 sites)	Region Total (N = 4 sites)	Region Total (N = 5 sites)	Region Total (N = 4 sites)	Region Total (N = 1 site)
Non-point source pollution	15	2	3	1	3	1	3	2	0
Hydrology	12	0	2	1	2	2	2	2	1
Nutrient studies	11	1	0	0	3	2	3	1	1
Restoration	11	1	3	1	2	1	2	1	0
Contaminants	10	1	1	0	2	1	3	1	1
Invasive Species	10	1	3	1	1	1	2	1	0
Sediment Transport / Processes	10	1	0	1	3	1	2	1	1
Physical Oceanography	9	2	0	1	2	1	2	1	0
Land Use (change/planning)	8	0	2	0	2	2	1	1	0
Other	8	0	0	0	3	2	0	3	0
Water Quality	7	1	3	0	2	0	1	0	0
Climate Change	6	0	0	0	3	1	1	0	1
Biodiversity	6	0	0	1	2	0	1	2	0
Energy Flow	4	0	0	0	1	1	1	0	1
Habitat Conservation	4	0	2	1	0	1	0	0	0
Plant/Animal Growth	4	2	0	0	1	1	0	0	0
Indicator Species	3	0	0	0	2	0	0	1	0
Cultural Resources	3	0	0	0	0	1	1	1	0
Human Impacts	3	0	0	0	1	1	0	1	0
Methodology Development	2	0	2	0	0	0	0	0	0
Plant/Animal Interactions	2	0	0	0	0	1	1	0	0
Management of Special Status Species	2	0	2	0	0	0	0	0	0
Storm Impacts	2	0	0	0	0	0	1	0	1
Sustaining Resources	2	0	0	1	0	0	1	0	0
Larval Transport	2	1	0	0	1	0	0	0	0
Community/Population Dynamics	1	0	0	0	1	0	0	0	0
Biological Oceanography	1	1	0	0	0	0	0	0	0

Appendix C: NERRS Strategic Plan (2005-2010)

strategic PLAN | 2005 - 2010

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vision | Healthy estuaries and coastal watersheds where coastal communities and ecosystems thrive.

mission | To practice and promote coastal and estuarine stewardship through innovative research and education, using a system of protected areas.

goals

1. Strengthen the protection and management of representative estuarine ecosystems to advance estuarine conservation, research and education.
2. Increase the use of reserve science and sites to address priority coastal management issues.
3. Enhance peoples' ability and willingness to make informed decisions and take responsible actions that affect coastal communities and ecosystems.

Introduction

For thousands of years, coastal and estuarine environments have provided people with food, safe harbors, transportation access, flood control, and a place to play and relax. The pressures on the nation's coast are enormous and the impacts on economies and ecosystems are becoming increasingly evident. Severe storms, climate change, pollution, habitat alteration and rapid population growth threaten the ecological functions that have supported coastal communities throughout history. As a network of 26 (soon to be 27) protected areas established for long-term research, education and stewardship, the National Estuarine Research Reserve

System has a unique role to play in keeping coastal ecosystems healthy and productive.

The reserve system is a partnership program between the National Oceanic and Atmospheric Administration and coastal states that has protected more than one million acres of coastal and estuarine habitat since the program was established by the Coastal Zone Management Act in 1972. NOAA provides funding, national guidance and technical assistance. Each reserve is managed on a daily basis by a lead state agency, non-profit organization or university with input from local partners. Through careful stewardship, innovative science and education, and relevant training programs, the reserves encourage careful management and protection of local estuarine and coastal resources.

The Coastal Zone Management Act created the reserve system to protect estuarine areas, provide educational opportunities, promote and conduct estuarine research and monitoring, and transfer relevant information to coastal managers. For the next five years, core reserve programs will focus on four priority topics:

- Impacts of land use and population growth;
- Habitat loss and alteration;
- Water quality degradation;
- Changes in biological communities.

The National Estuarine Research Reserve System's 2005-2010 Strategic Plan articulates how the strengths of the reserve system will be applied to address the major challenges of coastal management.

Priority Coastal Management Issues:

1. Land Use and Population Growth

The United States' exploding coastal population results in competing demands for clean water, beaches, recreational and commercial space, infrastructure and housing. In 2003, an estimated 153 million people lived in coastal counties, which is approximately 53% of the total US population. Pressure to develop land in coastal areas is escalating at more than twice the rate of population growth. Land use changes can significantly impact coastal and estuarine species and habitat. The Pew Ocean Commission reports that when more than 10% of a watershed is covered in impervious surface such as roads, roofs and parking lots, aquatic resources begin to degrade.1

Coastal population and land use demands are not only increasing, they also are changing. Demographic and socio-economic trends show that the backgrounds and interests of people who are moving to the coast may be different from those of traditional fishing, commerce, or beach communities. The way people value and understand their relationship to the coast is reflected in the personal, political and professional choices they make. To make wise coastal resource management decisions, we need to understand the relationships among estuarine ecosystems and changing landscapes and attitudes. National Estuarine Research Reserves encourage the development and use of science based knowledge and tools in local land use planning, community development, and stewardship of public and private property.

2. Habitat Loss and Alteration

More than half of the nation's coastal wetlands have vanished since European settlement.2 Estuarine and coastal environments continue to be altered and eliminated due to dredging, dams, recreational and commercial uses, flood and hazard mitigation, residential and infrastructure development, commercial port activities, and agriculture. Many of these activities disturb the physical, biological and chemical attributes of the estuary and therefore degrade the plants and animals that depend on the habitat to survive. Seagrass beds, marshes, shellfish, bird and fish populations can be affected by sedimentation, erosion, and hydrological, chemical or physical alteration of the habitat. Estuarine ecosystems also are vulnerable to coastal storms and sensitive to changes in climate and sea level. Coastal managers want to know more about how their choices influence coastal habitat and the species that live there. Better information will ensure that alternatives are considered for permitting, as well as planning and implementing successful restoration and mitigation efforts.3

Reserve research and monitoring programs increase the fundamental understanding of estuarine dynamics and add new information about the causes and consequences of changes in habitat quantity and quality. Research and stewardship programs at the NERRs also develop, implement and evaluate new techniques to restore and protect estuarine resources. Training programs and advisory services make this information available to professionals. Through education programs conducted at the reserves, students and citizens learn why these habitats are important and what they can do to keep them healthy.

3. Water Quality Degradation

Improving the condition of coastal water quality is a goal of the Coastal Zone Management Act and an ongoing struggle for all coastal regulatory agencies. Despite continuing local, state and federal investments, more than 20,000 beach closures were enforced in 20044 and more than 60% of estuarine waters were classified by the EPA as having degraded water in 2005.5 Excess nutrients and chemical and biological contamination can cause human health problems and threaten aquatic life.

The Reserve System has been collecting water quality data for ten years to quantify short term variability and long term changes in estuarine waters. Through monitoring and studying changes in water quality, the reserves investigate how human activity, weather patterns, and estuarine characteristics contribute to changes in water quality that affect ecological processes and, consequently, human health. Reserves apply the knowledge generated through research and monitoring to improve water quality through habitat protection, restoration, and training and outreach programs.

4. Changes in Biological Communities

Biological communities are changing as a result of invasive species, over-harvest, climate changes, pollution, and habitat destruction. Invasive species out-compete or consume native organisms; habitat alteration and destruction displace some species and create opportunities for others; and changes in parameters such as temperature and salinity can shift the distribution of plants and animals. Chemical contamination and nutrient enrichment damage habitat and can alter the structure of floral and faunal communities. Over-harvesting biological resources also can change community structure and threaten valuable species. These problems impact natural interactions and linkages and lead to cascading indirect effects throughout the ecosystems.

Reserve research, stewardship, education, and training programs focus on understanding how changes in biological communities affect the way estuaries function. To minimize the negative impact of these changes, reserves investigate and communicate how to balance public needs with the protection of increasingly susceptible natural resources.

A Local Approach to National Priorities

Land use and population growth, water quality degradation, habitat loss and alteration, and changes in biological communities are not the only topics that reserves work on, but these four have risen to the top as deserving of adequate and strategic investment for the national system. These four topics are high priority science and training needs for coastal managers.3 Reserve scientists, educators and land managers have identified these topics as locally and nationally important and appropriate to the mission of the National Estuarine Research Reserve System. Increased understanding about these topics will improve the reserve system's ability to protect and restore coastal watersheds and estuaries and empower individuals to make informed decisions. The nation's coasts and estuaries need to be managed, understood and appreciated at multiple scales. Through a network of locally oriented programs around the country, the reserve system provides insight into common information and management needs as well as data for use by local, regional and federal scientists and decision makers. Working at both the site level and as a national system, reserves have a greater impact than could be achieved through community efforts alone.

The goals, objectives and strategies outlined in this strategic plan will guide and support the National Estuarine Research Reserve System in its nation-wide efforts to improve coastal management, advance estuarine research, and educate current and future generations of coastal stewards.

Guiding Principles

- Strong partnerships between NOAA, state agencies and universities, and other local partners are critical to the success of the reserve system.
- The reserve system integrates science, education and stewardship on relevant topics to maximize the benefits to coastal management.
- Reserves serve as a catalyst and a focal point for demonstrating and facilitating objective problem solving and best management practices.
- Reserves engage local communities and citizens to improve stewardship of coastal areas.
- Reserves implement an ecosystem-based management approach.

Goal One:

Strengthen the protection and management of representative estuarine ecosystems to advance estuarine conservation, research and education.

Objectives:

1. Biogeographically and typologically representative estuarine ecosystems are protected through the designation of new reserves.

2. Biological, chemical, physical, and community conditions of reserves are characterized and monitored to describe reference conditions and to quantify change.

3. Reserve ecosystems are conserved through land acquisition, natural resource management and restoration.

Strategies:

- Identify and designate new reserves consistent with system-wide policy and available resources.

- Collect system-wide measurements of the short-term variability and long-term changes in the water quality, biotic communities and diversity, land-use and land cover characteristics of estuarine ecosystems to support effective coastal zone management.

- Collect baseline information about the biological, physical, chemical, and socio-economic parameters of reserve biological and human communities.

- Integrate NERRS monitoring, data management, education and training capabilities in regional ocean observing systems.

- Implement land acquisition plans to enhance the long term integrity and diversity of reserve habitats.

- Restore and actively manage reserves' natural resources to meet local habitat and human use goals.

- Work collaboratively with other programs to evaluate and apply advanced technologies and tools to support effective coastal management.

- Provide facilities and support to manage the natural resources within reserve boundaries.

Goal Two:

Increase the use of reserve science and sites to address priority coastal management issues.

Objectives:

1. Scientists conduct estuarine research at reserves that is relevant to coastal management needs.

2. Scientists have access to NERRS datasets, science products and results.

3. The scientific community uses data, tools and techniques generated at the NERRS.

Strategies:

- Understand coastal decision maker science and training needs through needs assessments, coastal management science needs surveys, etc.

- Work collaboratively with other programs to conduct research on priority management issues in the reserves.

- Offer Graduate Research Fellowships to master's and doctoral students to conduct science that is relevant to coastal management and to train students in estuarine science.

- Deliver monitoring and observation data to the scientific community.

- Disseminate reserve science through publications, outreach and technology transfer.

- Generate time-series data and empirical studies to describe the ecological condition of reserve habitats.

- Promote reserve science products through web sites, communication materials, and other avenues to meet the needs of diverse stakeholders.

- Increase visibility and reinforce the credibility of NERRS science through communication efforts about NERRS research and monitoring.

- Attract scientists and practitioners to use reserves as reference sites.

- Conduct and facilitate relevant research in reserve watersheds.

- Synthesize reserve data into information for use in decision making.

- Conduct and facilitate research into education effectiveness and behavior change.

- Ensure that reserves have facilities and research support to meet the needs of visiting scientists and staff.

Scientist: *A person who uses principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses.*

Goal Three:

Enhance people's ability and willingness to make informed decisions and take responsible actions that affect coastal communities and ecosystems.

Objectives:

1. People are aware of the ecological, economic, historical, and cultural importance of estuarine resources.

2. People understand how human choices and natural disturbances impact social, economic, and estuarine ecological systems.

3. People apply science-based information when making decisions that could impact coastal and estuarine resources.

Strategies:

- Provide educational opportunities that increase students' understanding of estuarine science and technology.
- Implement and participate in public programs and events to raise awareness and understanding about estuaries and the NERRS.
- Produce and distribute educational materials and web-based products that raise public awareness about estuaries, the NERRS, and NERRS education products.
- Train teachers to educate students about coastal watersheds and estuaries.
- Deliver monitoring and observing data to diverse user groups in a useful format.
- Improve the willingness and ability of communities to restore and protect coastal ecosystems.
- Provide science-based information and training to individuals and organizations.
- Assist restoration practitioners in developing and applying effective restoration techniques.
- Implement volunteer programs to engage local citizens in advancing the goals of the reserves.
- Conduct programs to encourage people to make personal choices that reduce their impact on coastal resources.
- Evaluate programs to determine how people apply information and knowledge.
- Build and maintain educational facilities and interpretive displays.

Appendix D. NERRS Site Profile Status

Sites completed profile

	Year published
ACE Basin, SC	**2001**
Delaware	**1999**
Elkhorn Slough, CA	**2002**
Great Bay, NH	**1992**
Jobos Bay, PR	**2002**
Kachemak Bay, AK	**2003**
Old Woman Creek, OH	**2004**
Rookery Bay, FL	**2003**
Sapelo Island, GA	**1997**
Tijuana River, CA	**1992**
Waquoit Bay, MA	**1996**
Weeks Bay, AL	**1996**
Hudson River, NY	**2006**

Sites planning profile

	Anticipated publication year
Apalachicola Bay, FL	2006
Chesapeake Bay, MD	2008
Chesapeake Bay, VA	2007
Grand Bay, MS	2006
Guana-Tolomato-Matanzas, FL	2006
Jacques Cousteau, NJ	2007
Narragansett Bay, RI	2007
North Carolina	2006
North Inlet-Winyah Bay, SC	2006
Padilla Bay, OR	2007
San Francisco Bay, CA	2007
South Slough, OR	2006
Texas-Mission Aransas	2009
Wells, MA	2006

Appendix E. Key milestones anticipated for achieving NERRS research goals

Research Goal	Milestones*	Products*	Y1	Y2	Y3	Y4	Y5
1. Biological, chemical, physical, and ecological conditions of reserves are characterized and monitored to describe reference conditions and to quantify change.	Site Profiles completed	3 site profiles/year	x	x	x	x	x
	Revise SAV/Emergent Biomonitoring protocol	Updated protocol	x				
	Summarize initial SAV/Emergent Biomonitoring projects	Synthesis document	x	x			
	Implement NERRS Habitat Classification System	At least 3 sites employ/year	x	x	x	x	x
	Develop a NERRS Remote Sensing Strategy	NERRS remote sensing guidance document	x	x			
	Integrate NERRS monitoring data with national and regional IOOS efforts	Partners use NERRS real-time and archived data	x	x	x	x	x
2. Scientists conduct estuarine research at reserves that is relevant to coastal management needs and increases basic understanding of estuarine processes.	Revise Graduate Research Fellowship (GRF) priority research areas	Updated GRF focal areas	x	x			
	Revise NERRS Research Database that archives and tracks research projects with the NERRS	Functional NERRS Research Database	x				
	Populate NERRS Research Database with research projects that are occuring or have occurred in the recent past (5 years) at reserves	Current, ongoing, and past research projects with NERRS are archived	x	x	x	x	x
	NERRS works with CICEET to improve coordination and delivery of relevant science	NERRS research products are accessible, CTP workshops deliver information to broad user audiences	x	x	x	x	x
	Complete a regional and/or national assessment of NERRS environmental conditions	A NERRS "Report Card" document			x	x	
3. Scientists have access to NERRS datasets, science products and results.	CDMO capabilities are assessed in relation to expanding NERRS data collection and delivery needs	CDMO and ERD identify options to manage increasing data loads and data visualization needs	x	x	x		
	NERRS Research Database is available for public access onlinez	Searchable database of research projects is available online for public access/information	x	x			
	A NERRS Special Journal Issue is published to highlight biological monitoring and research in the field	Published Special Journal Issue		x			
	A NERRS Special Journal Issue is published to highlight NERRS Habitat mapping/Land use change monitoring and remote sensing research	Published Special Journal Issue					x
	Develop a method to deliver biological monitoring and habitat mapping information to the public through CDMO	Biomonitoring information and habitat maps are made available to the public	x	x	x		
4. The scientific, coastal management and education communities, as well as the general public, use data, products, tools, and techniques generated at the NERRS.	Regularly evaluate NERRS Research priority needs	Up-to-date NERRS research priorities		x		x	
	Revise and update SWMP Plan	Revised SWMP Plan	x	x			
	Conduct a SWMP External Review	Evaluated program to guide future development	x	x			

* Some milestones and products will require additional resources.

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Appendix 3: North Carolina Coastal Habitat Protection Plan – Reseach and Monitoring Needs

RESEARCH AND MONITORING NEEDS IDENTIFIED BY THE NORTH CAROLINA COASTAL HABITAT PROTECTION PLAN

BY

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August 2005

Introduction

With passage of the Fisheries Reform Act of 1997, the North Carolina General Assembly established the Coastal Habitat Protection Plan (CHPP) program within the North Carolina Department of Environment and Natural Resources (DENR). The Act (General Statute 143B-279.8) requires preparation of a Coastal Habitat Protection Plan, the goal of which is "long-term enhancement of coastal fisheries associated with each coastal habitat." The divisions of Marine Fisheries (DMF), Water Quality (DWQ), and Coastal Management (DCM) were designated as the lead agencies for the development of the CHPP document. Specifically, the CHPP is to:

- Describe fisheries habitats and their biological systems;
- Evaluate the functions, fisheries' values, status, and trends in the habitats;
- Identify existing and potential threats to the habitats and impacts on coastal fishing; and
- Recommend actions to protect and restore the habitats.

To fully attain the CHPP goal, numerous research and monitoring needs were identified by the CHPP Development Team [including staff from the DMF, DWQ, and DCM, the Division of Environmental Health (DEH), and the Wildlife Resources Commission (WRC)] and suggested in the CHPP. By December 31, 2004, the three regulatory commissions responsible under the Act formally adopted the CHPP (Street et al. 2005), including the research and monitoring needs contained therein. The purpose of this research report is to summarize these research and monitoring needs to encourage and facilitate acquisition of this information by the research community. Meeting these research and monitoring needs will aid in implementation of CHPP recommendations.

Current related initiatives

The necessity for conducting cooperative, integrative research and monitoring in coastal settings has been cited in documents recently released by various organizations.

A report generated by the Pew Oceans Commission in May 2003 proposed the following:

"We know the oceans are in crisis. Unfortunately, as the nature, scale, and complexity of threats to marine ecosystems have increased, our national investment in ocean science and research has stagnated…The nation must increase investment in ocean science and research, particularly broader programs to monitor and to understand ecosystems…We need a deeper understanding of the effects of both natural and anthropogenic change on marine ecosystems as well as of the oceans' interaction with terrestrial ecosystems and the atmosphere. Increased capacity is needed in four areas to improve applied ocean science and research:

1. acquisition of new information, knowledge, and understanding;
2. monitoring to evaluate status and trends;
3. capability to integrate and synthesize existing and new information;
4. sharing of information and knowledge with the public."

Released in September 2004, the report of the U.S. Commission on Ocean Policy similarly recommended that the National Oceanic and Atmospheric Administration (NOAA) create an expanded, regionally-based cooperative research program that coordinates and funds collaborative projects between scientists and fishermen.

More recently, another federal document, the Environmental Protection Agency's National Coastal Condition Report II (EPA 2005), emphasized the importance of coordinated monitoring efforts within coastal habitats. The report noted that while trying to make best use of available data to characterize and assess estuarine systems, the assessment was based on a limited number of ecological indicators for which consistent data sets were available to support estimates of ecological condition on regional and national scales. The report goes on to say that a multiagency and multistate effort is needed over the continuing decade, to achieve a truly consistent, comprehensive, and integrated national coastal monitoring program that can accurately assess the health of coastal ecosystems.

In North Carolina, the CHPP identifies topics for coordinated interagency research. Because North Carolina's coastal fishery resources exist within a system of interdependent habitats, it is necessary to approach habitat management on the basis of ecosystem integrity and understanding the linkages among all coastal habitats and the outside forces that affect them. Research needed to provide the basis for ecosystem management is, of necessity, multi-disciplinary. In addition, it is also recognized that no environmental issue can be fully evaluated without considering the economic impact of alternative management actions designed to minimize degradation of the ecosystem. Determining effective management actions will thus require the integration of biological, chemical, physical, social, economic, legal and political sciences.

CHPP Research and Monitoring Needs

Table 1 describes research and monitoring needs identified directly or indirectly within the CHPP document. The purpose of Table 1 is to provide researchers and managers a quick reference guide to support their research/monitoring proposals with needs identified in the CHPP text. Thus, there are page references that serve to provide additional context for each research/monitoring need. For the purpose of clarification, the text of selected research and monitoring opportunities has been rephrased from their appearance within the CHPP, so that particular concepts may better function as discrete, "stand alone" ideas.

The research and monitoring needs in Table 1 are grouped into the following categories:

- Stormwater runoff
- Strategic Habitat Areas
- Fish-habitat relationships
- Docks and marinas
- Estuarine erosion and shoreline stabilization
- Boating related
- Beach nourishment
- Fishing gear impacts
- Managing non-native species

- Chemical effects
- Water supply
- Habitat status and trends
- Evaluating existing management measures
- Comprehensive water quality monitoring

Unfortunately, no fuding mechanisms have been developed specifically intended to support these identified needs. Interested researchers should pursue all available funding sources. The members of the CHPP development team identified in the CHPP are available to discuss these research and monitoring needs.

Literature Cited

Environmental Protection Agency. 2005. National Coastal Condition Report II. EPA-620/R-03/002. Office of Research and Development/Office of Water, Washington, DC. 271 p.

Pew Oceans Commission. 2003. America's Living Oceans: Charting a Course for Sea Change. A Report to the Nation. Pew Oceans Commission, Arlington, VA. 144 p.

Street, M.W., A.S. Deaton, W.S. Chappell, and P.D. Mooreside. 2005. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, NC. 656 pp.

U.S. Commission on Ocean Policy. 2004. An Ocean Blueprint for the 21st Century. Final Report of the U.S. Commission on Ocean Policy - Pre-Publication Copy. Washington, DC. 455 p plus appendices.

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Stormwater runoff	***The major cause of water quality degradation in coastal North Carolina today is stormwater runoff. While methods to control direct discharges to surface waters have greatly improved over time, there are still many questions concerning the interaction of stormwater runoff and fish habitat, and how to effectively control non-point runoff of pollutants. Research is needed to identify the causative relationships between ecosystem conditions and land cover, hydrology, and runoff characteristics. Identifying causative relationships will allow managers to predict the impact of increasing development on coastal ecosystem conditions and prescribe management actions.***			
	Complete watershed mapping of hydrology/land cover and monitoring of downstream water quality in order to build models predicting runoff characteristics. Water quality parameters measured should include those determined to affect the survival of sensitive biological indicators (e.g. submerged aquatic vegetation, oysters).	R-M	*49, 69, *75, 77, *88-89, 109-110, 135, 332, 340-343, 412	
	Determine the relationship between changes in drainage characteristics and changes in distribution and status of sensitive biological indicators in receiving waters.	R	78	
	Identify water quality parameters (e.g., TSS, chlorophyll a, nutrients, color) and standards (e.g. average concentration, variation in concentration) that are necessary to support sensitive biological indicators.	R	34, 63, 66, 80, 89, 115, 127, 131, 224-225, *257, *274, *286-287, 335, *340, *472	
	Assess the conditions and ecological functions of black water ecosystems to determine their value as strategic buffers/filters between upland runoff and coastal fisheries habitats.	R-M	319	
	In blackwater swamp systems, assess dissolved oxygen (DO) levels and associated biological impacts, differentiating between DO derived from inflow of swamp waters and DO derived from anthropogenic nutrient loading.	R-M	34-35, 64, 85, 89, 100, *101, *103-104, *223-224	
	Evaluate the cumulative amount and extent of land cover and hydrological changes that can be accommodated by natural ecosystems before reaching some critical threshold of change in ecosystem integrity* within a watershed. ***Ecosystem integrity** is the capability of a system to support services of value to humans.	R	86, 88	
	Determine stormwater control strategies needed to prevent watersheds from reaching the critical threshold of change in ecosystem integrity.	R	79, *88, *100, *111-112, 131	
Strategic Habitat Areas	***All aquatic areas are important for the propagation and production of fish and shellfish resources. However, some specific areas stand out as being of key importance for certain species or biological communities, and the overall maintenance of ecological stability. Identification of these Strategic Habitat Areas (SHAs) is a high priority, but we lack sufficient data and tools to fully identify them. Research items below were noted in the CHPP as being necessary to help fill these information gaps so that North Carolina's coastal ecosystem can be adequately protected.***			
	Develop ecologically based criteria for locating and defining SHAs, including biological indicators of ecosystem integrity.	R	62, 268, *292, 462, 466, *483	Advisory Committee established

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Strategic Habitat Areas	Expand and improve juvenile fish sampling programs to provide regional information on status and trends in juvenile utilization of various types of nursery habitat and their contribution to production of fishery stocks. This information could serve as a basis for identifying or validating important strategic habitat areas.	M	263, *272, *380, 383-384	
	Develop techniques/technology to improve and expedite aquatic habitat mapping in order to identify the spatial extent of SHAs.	R	*483	Being addressed by shell bottom and SAV mapping
	Determine if and where foraging or refuge habitat is more limiting to fish production for that area than spawning or nursery habitat.	R	61-62, 209-210, 266, 268, 324-325, 375, 381, 458, 481	
	Identify important spawning areas for key fishery species and demonstrate their importance in terms of contribution to fisheries production.	R	53, 209, 266, 326, 378, 458, 481	
	Assess use and importance of nearshore hard bottom areas as spawning or secondary nursery areas for estuarine-dependent or reef species.	R	*458-459	
	Determine if there are core habitat areas that are key to submerged aquatic vegetation (SAV) expansion, particularly in the Albemarle Sound system, that justify special monitoring and protection.	R	*272	
Fish-habitat relationships	***There are many gaps in information regarding the specific relationships between habitat characteristics and viable fish populations. Few clear cause and effect relationships have been demonstrated between changes in habitat condition and status of fish populations due to the complexity of the coastal system and lack of data. A better understanding of fish-habitat relationsips is the cornerstone to fish habitat protection.***			
	Determine the effect of bivalve shellfish location and filtering capacities on water quality parameters, such as nutrients, sediments, and chlorophyll a.	R	*108, 204	
	Evaluate recruitment enhancement of oysters and other key organisms provided by low-density cultch planting in nursery areas.	R	*210	
	Fully evaluate the role of SAV in the spawning success of red drum, weakfish, spotted sea trout, and other important species.	R	*266	
	Determine spatial and biological characteristics of SAV beds that maximize their ecological value to important finfish and invertebrate species. This information will aid in design of seagrass restoration projects and location of SHAs.	R	*267	
	Examine the effect of spatial connectivity between habitats (ie. marsh edge and SAV) on juvenile predatory fish use, survival, growth, and abundance (i.e. red drum, spotted seatrout).	R	216, *269, *326, 381	

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Fish-habitat relationships	Determine if long-term declining trends in bay scallop and blue crab populations are related to declines in, or degradation of, SAV.	R-M	*272	
	Determine what pocosin areas are directly used by estuarine fishes, and the contribution of those areas and fish to overall production in the estuary.	R	*322	
	Assess if reef fish populations in North Carolina are limited by the amount of available hard bottom habitat by comparing differences in fish abundance before and after artificial reefs are added using a Before-After-Control-Impact Paired Series (BACIPS).	R	*463	Coordinate with similar work
	Determine if and to what extent artificial reefs in North Carolina simply concentrate available fish or if they effectively increase fish biomass.	R	*463	
	Determine the critical frequency and extent of hypoxia and anoxia, above which significant changes in biotic community structure occur.	R-M	104, 223, 318	
	Determine the critical amount and quality of living and dead shell bottom in a water body below and above which significant changes in biotic community structure (e.g., SAV, oyster reef) occur.	R-M	*215	
	Identify biological indicators of ecosystem integrity that also indicate viable populations of traditional fishery species.	R	13, 135, 262, 289, 372	Coordinate with existing work (APNEP)
	Locate potential SAV and oyster restoration sites using a combination of seed/larval transport, water quality, physical habitat models, coincidence with watershed restoration efforts, and other available information.	R	*218, 224, 230, *257, *267, *272	Coordinate with existing work
Docks and Marinas	***As coastal, human population increases, there is a continuing demand for additional individual and multi-slip boat docking facilites and marinas, and decreasing availability of highly suitable locations. More answers are needed regarding the direct, indirect, and cumulative effects of these facilities and their use on fish habitat so that future dock and marina siting guidelines can minimize habitat impacts.***			
	Determine if marina basins in freshwater and low-salinity nursery areas produce toxic chemicals at sufficient concentrations and critical times to impact local fish populations (especially considering egg and larval life stages).	R-M	118, *121	
	Determine if existing dock siting criteria allow adequate light beneath dock structures to maintain SAV and coastal wetland habitat. If existing criteria result in adverse effects on SAV or coastal wetlands, modified dock siting specifications that allow adequate light penetration should be identified.	R	*279	Preliminary DMF research available
	Analyze marina development, design, siting and operation to determine the best management practices to minimize impacts of multi-slip docking facilities.	R	*123	Advisory committee established (Sea Grant)

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Docks and Marinas	Quantify the cumulative effect of multi-slip docking facilities and associated development on water quality, characteristics of runoff, and the impacts on adjacent fish habitat.	R-M	*125, *279, *391	Advisory committee established (Sea Grant)
	Evaluate the impact of dock-associated prop dredging on shallow nursery habitats.	R-M	*391	
Boating related	***In addition to the effects of docking structures, information is needed on the individual and cumulative effects of boat use on coastal waters and habitat. As boat use changes over time, additional information may also be needed.***			
	Assess the impact of jetties on successful larval passage through inlets into estuaries, particularly in Pamlico Sound where inlets are limited.	R-M	*83	
	Examine the relative contribution of channel deepening to saltwater intrusion and evaluate subsequent oyster mortality (i.e. from predation) in order to determine appropriate management actions.	R-M	*228	
	In areas of heavy boat traffic and extensive SAV beds, periodically assess the level of damage to SAV from prop scarring.	R-M	*277	Some NOAA work
	Determine what effect the Ocean Dredge Material Disposal Site (ODMDS), located near the mouth of the Cape Fear River, has had or will have on nearby hard bottom habitat.	R	*469	
	Determine the impact of chronic oil pollution from boating and runoff on estuarine nursery areas.	R-M	*122-123	
	Determine the impact of waves propagated from boat operations on adjacent marsh and shell bottom shorelines.	R-M	*222, *350	
Estuarine erosion and shoreline stabilization	***Shallow water habitats adjacent to the estuarine shoreline are critical to North Carolina's coastal fish populations. Therefore, managing shoreline stabilization activities in a manner that minimizes habitat impacts is an important issue. Research that aids in understanding shoreline processes and the effect of man-made structures on the estuarine environment will help in implementing the CHPP recommendation to revise estuarine and public trust shoreline stabilization rules for protecting fish habitat.***			
	Periodically assess where and how much of the estuarine shoreline is hardened. Accurate information is key to assessing the level of impact to fishery resources.	M	*347	Preliminary DMF research available
	Examine if and how oyster shell could be utilized as an alternative to rock or wooden stabilization structures to create “living shorelines” that are effective in stabilizing the shoreline.	R-M	*349, *392	
	Develop accurate coast-wide estuarine erosion rates to assess sea-level rise and storm impacts, determine adequate development guidelines, and shoreline stabilization policies that minimize impacts on fish habitat (e.g., soft bottom, wetlands, shellfish).	R-M	*105, *349	DCM workgroup discontinued

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Beach nourishment	***The demand for beach nourishment projects has greatly increased in recent years. It is therefore increasingly important to fully understand the long-term consequences of this activity to the coastal system and fish populations, so that an ecologically based, comprehensive beach and inlet management plan can be prepared, per the CHPP recommendation.***			
	Compile detailed mapping studies of coastal subtidal bottom in a comprehensive and comparable manner in order to evaluate changes and trends in substrate character.	R-M	*370	Pilot project completed
	Determine if and to what extent sand from nourished beaches is transported onto nearshore hard bottom and the effect of sand deposition on the hard bottom habitat and associated biological community.	R-M	*465	
	Assess the cumulative impact and effectiveness of beach bulldozing and determine appropriate guidelines for inclusion in a coastal beach management plan.	R-M	*393	One study completed
	Assess direct and indirect effects, and cumulative impacts of beach nourishment activities on surf-zone organisms (finfish and invertebrates), their habitats and recovery rates from individual and cumulative nourishment events.	R-M	*398, *402	
Fishing gear impacts	***While most bottom disturbing fishing gears have been restricted from use in highly sensitive areas, the effect of some gears is still uncertain, and more information is needed to determine needed fishery management changes. Information regarding fishing gear impacts will help implement the CHPP recommendation to protect structured habitats from fishing gear effects.***			
	Measure in situ rates of growth, mortality, and recruitment for selected benthic organisms that are regularly exposed to trawling.	R	*405	
	Evaluate the effect of trawling on benthic algal growth and primary productivity overall.	R	*405	
	Conduct large-scale, long-term experiments with and without fishing pressure, rather than short-term, small-scale studies, to examine and quantify cumulative fishing impacts and recovery patterns on estuarine soft bottoms and benthos.	R-M	*407	
	Monitor the impact of hook and line fishing and anchoring on hard bottom.	R-M	*467	
	Determine whether fishing gear impacts and/or other factors are causing the decline observed in bay scallop abundance.	R	*281	
	Assess turbidity impacts to SAV from mechanical shellfish harvesting gear in southeast Pamlico Sound, Core Sound, and other mechanical clam harvest areas.	R-M	*282	
	Assess the effects of shrimp and crab trawling; crab, oyster, clam, or scallop dredging; and clam kicking on SAV, particularly in Core and Bogue sounds.	R-M	*284	
	If turbidity or other gear impacts from operation of bottom disturbing fishing gear degrades nearby SAV habitat, determine what additional protective buffers are needed between SAV and areas where such gear are used in order to minimize impacts.	R	*292	
	Identify the location and duration of trawling over soft bottom habitat, as well as over structured habitats (shell bottom, hard bottom and SAV), and quantify the effects of trawling on the habitats.	R-M	*405	
	Determine turbidity levels generated by different commercial fishing gear configurations and the subsequent rates of redeposition at various distances from the origin under varying wind and current conditions.	R	*405	

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Fishing gear impacts	Compare the significance of natural forms of disturbance on soft bottom habitat to that of trawling effects on soft bottom habitat.	R-M	*405	
	Sample areas normally subjected to trawling to describe the local benthic community, identifying seasonal cycles of species abundance and recruitment, to determine the times of year that benthos would be most sensitive to trawling disturbance.	R-M	*405	
Managing non-native species	***The accidental or intentional introduction of non-native species is a growing issue in natural resources management. Understanding the effect of non-native species on the ecological integrity of our native ecosystems is necessary for effective ecosystem management.***			
	Conduct testing on the aquacultural use of non-spawning, non-native oysters before decisions are made opposing or supporting introduction.	R	*229	Research ongoing
	Compare the fish habitat value of Eurasian watermilfoil relative to native vegetation.	R	*291	
	Develop ways to prevent proliferation of non-native species by sterilizing ballast water, testing non-native species before introduction, and assessing legal mechanisms to prevent introductions.	R-M	*129	
Chemical effects	***Growing use and disposal of chemicals in support of modern lifestyles has undoubtedly had an effect on the viability of organisms in receiving waters. While there is some information available on the toxicity of certain chemicals to selected organisms, under certain conditions, more work is needed to fully evaluate the potential impact of chemical pollution on fisheries resources.***			
	Identify pesticides that are "safe" for spraying over open waters, and for those pesticides whose toxicity is impacted by salinity, appropriate application rates for controlling mosquitoes.	R	*125	
	Determine the sources, prevalence, and effects of hormone-altering chemicals on important fish species in North Carolina's coastal waters.	R-M	*118	
	Examine the effects of existing contaminant levels and other environmental stressors on water quality, benthic food organisms, and fish.	R-M	118, 224, *411, *469	
	Evaluate the biological impact of any new materials (wood, plastic, cement, etc.) used in water-dependent structures on the aquatic ecosystem.	R	*121, *226	
Water supply	***With increasing demands for fresh water, the allocation of existing water resources among direct human uses and the needs of native fish and wildlife species is becoming an increasingly difficult issue.***			
	Assess the impact of increasing municipal, industrial, and/or agricultural surface water withdrawals as well as reservoir management on instream flows (water column habitat) on dependent anadromous fish populations in coastal rivers.	R	*73	
	Assess groundwater supplies in coastal counties to determine the potential environmental consequences of increasing subsurface water withdrawals.	R-M	*74	
	Determine effects of brine effluent disposed from filter backwash and reverse osmosis water treatment facilities on biological communities in coastal receiving waters.	R-M	*128-129	

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Habitat status and trends	***Determining the status and trends in condition of fish habitats is vital in evaluating the need and effectiveness of management actions intended to protect them.***			
	Conduct change analysis of existing shell bottom by DMF's Shellfish Habitat and Abundance Mapping Program on a subset of priority areas. Prioritization should include consideration of functional significance, economic value, and the magnitude of growth and development affecting the area.	R-M	*211	
	Determine the status of hard clams, sheepshead, black drum, and resident non-fishery species (e.g., oyster toadfish) as indicators of shell bottom conditions, using fisheries-independent-data.	R-M	*215	
	Evaluate status and trends in coast-wide distribution and condition of SAV at regular intervals. Comprehensive maps of all existing and potential SAV habitat should also be developed.	M	*272, *291	Workgroup established
	Determine wetland restoration success criteria based on long-term monitoring of hydrology, soil, and vegetation characteristics at established reference sites.	R-M	*332	Coordinate with EEP
	Determine the cumulative impact of small wetland losses on the distribution and abundance of wetland types in selected watersheds. The cumulative losses could then be related to the nature and extent of development pressure in those watersheds in order to formulate a model predicting untracked losses in other watersheds.	R-M	*339	
	Evaluate the susceptibility of freshwater wetlands to soil loss from sulfate metabolism in coastal North Carolina.	R	*352	
	Use biological indicators of habitat condition and coastal ecosystem integrity to help determine overall status and trends for the coastal ecosystem in North Carolina.	M	13, 17-19, 64, 66, 104, 135, 215, 223, 262, 289, 318, 372	Workgroup established
Evaluating existing management measures	***Prior to establishing new or additional management measures, resource agencies must first evaluate and determine if existing management measures are adequate and effective in achieving their intended management goals.***			
	Evaluate the functional viability of shellfish (primarily oysters) in closed shellfishing waters and their value as protected shell bottom habitats.	R-M	*231	
	Assess the N.C. Pesticide Board's policies on aerial drift of pesticides and suggest changes if necessary to ensure adequate protection for aquatic life and water quality from pesticide impacts.	R	*126	
	Evaluate water quality conditions and effectiveness of the nutrient reduction strategies in the Neuse River and the Tar-Pamlico River.	R-M	*133	On-going
	Evaluate effectiveness of ORW and HQW rules in protecting SAV and other habitats.	R-M	135, *292-293, *337	
	Evaluate the CRC's beach nourishment rules and determine changes needed to minimize impacts from beach nourishment and dredge disposal on soft bottom communities.	R	*277	

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Table 1. Research needs identified in the North Carolina Coastal Habitat Protection Plan.

Issue	Description of Need	Type^	CHPP page reference*	Status (Aug 05)
Evaluating existing management measures	Examine and propose revisions to current CRC shoreline stabilization rules using best scientific information to minimize impacts from this activity to soft bottom and wetlands, particularly intertidal estuarine shorelines.	R	*391-392	
Comprehensive water quality monitoring	***The overall status of water quality in North Carolina has been difficult to evaluate because of the variety of uncoordinated water quality monitoring efforts covering different areas over different time periods. The gaps in completing a comprehensive evaluation of coastal water quality are many. Some of these needs were noted in the CHPP and are listed below.***			
	Expand water quality monitoring in North Carolina's nearshore ocean waters to improve our understanding of existing conditions and processes in coastal waters and the effect of estuarine inputs and human activities on local water quality.	M	*66	
	Assess water quality trends and causes of degradation in tidal creek systems, particularly in southern coastal counties that are highly important nursery and shellfish areas and are under intense development pressure, and determine effective preventive and restoration measures.	R-M	*100-101	
	Monitor the effect of estuarine water quality, particularly nutrient and sediment loading, on nearshore ocean hard bottom.	R-M	*469	
	Additional water and tissue analysis at hard bottom sites is needed to determine if the benthos of the hard bottom community or the surrounding waters exhibit toxin levels that exceed designated levels of concern.	M	*469-470	
	Assess the impact of historic and recent wetland drainage activities on coastal water quality.	R-M	*80, 222, *340	
	Assess the effects that oceanfront septic systems have on nearshore coastal water quality.	R-M	*116	
	Once the appropriate water quality conditions for protection of SAV are determined, current water quality monitoring stations and methods should be re-evaluated and modified (if necessary) so that data adequately assess if SAV-based water quality criteria are being met (both baseline and potential SAV habitat). The Neuse, Tar-Pamlico and White Oak basins should be a high priority for monitoring of SAV and water clarity.	R-M	*287	Contingent on research results

^R=Research, M=Monitoring, and R-M=Research that can form the basis of monitoring
*Specific research need extracted from the CHPP (wording very similar).

Appendix 4: NERRS Habitat Classifications and Land Cover Protocols

Appendix 4: Habitat Classification and Land Cover Protocols

4.1: Habitat Classification Methods

A primary objective of SWMP Phase 3 is to evaluate changes over time in estuarine habitats and coastal land cover. Initial activities in accomplishing this are to document baseline conditions of habitats within the Reserves and land cover conditions for watersheds associated with the Reserve components. In support of these efforts, the NERRS has recently adopted a habitat classification scheme to consistently describe ecosystems throughout the Reserve System and at various levels of detail (Kutcher et al. 2005). The NERR Habitat Classification scheme is a modified combination of classification schemes established for the U.S. Geologic Survey (Anderson et al. 1976), U.S. Fish and Wildlife Service (Cowardin et al. 1979) and NOAA Coastal Change Analysis Program (C-CAP 2004). The NERR Habitat Classification scheme uses a nested hierarchical structure to describe habitat and land cover conditions at 5 levels of detail: System, Subsystem, Class, Subclass, and Descriptors. Each habitat category is assigned a unique numerical code for each hierarchical level (see Section 4.6). This allows the classified data to be efficiently analyzed and summarized at any of the 5 levels. For example, a stand of *Spartina alterniflora* would be assigned labels as presented in Table 4.1. Additional modifiers may also be designated by a Reserve to describe unique local habitat conditions.

Table 4.1. Hierarchical Classification Labels for *Spartina alterniflora.*

Level	Code	Label
System	2000	Estuarine Habitat
Subsystem	2200	Estuarine Intertidal Haline
Class	2260	Estuarine Intertidal Haline Emergent Wetland
Subclass	2261	Estuarine Intertidal Haline Emergent Wetland - Persistent

Initially, the NCNERR conducted a pilot project at the Zeke's Island component to evaluate the NERR Habitat Classification scheme and to develop standardized methods for consistent application of the scheme. The protocols and scheme were subsequently used to classify habitats for the Masonboro Island, Rachel Carson and Currituck Banks NCNERR components.

The NCNERR habitat classification approach alternated between field surveys and digital image analyses (see Table 4.2). Habitat analyses and area calculations were conducted using ESRI GIS software. Habitat features were digitally delineated from best-available ortho-rectified True Color aerial photography collected in 2002 and 2004. Ancillary information was provided by digital Color Infrared (CIR) imagery collected in 1998. The CIR data depict differences in substrate moisture content and vegetation chlorophyll *a* levels. These data are helpful for distinguishing upland from estuarine and marine conditions, and plant species with different leaf morphologies.

Non-aquatic habitat features were mapped if they covered an areal extent equal to or greater than a minimum mapping unit (mmu) of approximately 1/4 acre (100' x 100'). Linear and small features were delineated if they were greater than, respectively, 10' x 50' or 50' x 50' and were deemed to be ecologically significant. Each habitat feature was defined as a polygon with associated labels (attributes) for each of 4 hierarchical classification levels: System, Subsystem, Class and Subclass. Descriptor (level 5) labeling of habitat features requires more extensive field surveys and will be added in the future as time and priorities allow. Maps and analysis of the habitat classification for each Reserve component are provided in their respective chapters. Section 4.3 includes pictures and descriptions of habitat subclasses found in the NCNERR.

Table 4.2. NCNERR habitat mapping approach during pilot project

Step	Description
1	**Identification and acquisition of best-available digital aerial images: 2002 and 2004 True Color aerial photos (0.5' – 2' resolution); ancillary 1998 Color Infrared imagery (3.3' resolution).**
2	**Initial field survey to document conditions and geocoordinates of representative patches of habitat types. The survey data are used as habitat "signatures" as an aid for aerial photo interpretation.**
3	**Initial digital delineation of habitat polygons. Spatial definition was based on the 2002 - 2004 True Color aerial photography. Habitat labeling incorporated additional moisture and chlorophyl level information from the 1998 Color Infrared imagery.**
4	**Calculation of areal statistics, based on the preliminary habitat classification.**
5	**Field check of preliminary habitat map to confirm delineations that are confident and resolve those that are uncertain.**
6	**Revision of habitat delineations and labels based on the field check.**
7	**Field check of revised habitat classification, to verify delineation and labeling.**
8	**Preparation of distribution-quality map of final habitat classification.**
9	**Calculation of areal statistics using final habitat data.**
10	**Reserve staff review of habitat map and areal statistics.**
11	**Preparation of final habitat map, statistics and graphics.**

The classification identified 26 subclasses in 5 habitat systems within the NCNERR. Habitat occurrence for the four NCNERR components is presented in Table 4.3 as the percent of the site total (non-aquatic acres) for each subclass. The values for the three most prevalent habitat subclasses are circled for each site. Statistics represent habitat distribution as delimited by the anthropogenic management boundaries of the Reserve, rather than natural boundaries such as watersheds. NCNERR Habitats are summarized as follows:

- Approximately half of the non-aquatic habitat area at the Rachel Carson, Masonboro Island and Zeke's Island Components is Estuarine Intertidal Persistent Wetland. This is primarily *Spartina alterniflora*. For Currituck Banks, Estuarine Supratidal Persistent Wetland is predominate, identified as 17% of the habitat area. The major species is *Spartina cynosurides*.

- The second most prevalent habitat is variable by site, including Upland Supratidal Sand (Dune) at Masonboro Island and Zeke's Island, and Estuarine Intertidal Sand at Rachel Carson. At Currituck Banks, Upland Supratidal Forest Mixed covers 11% of the area, the largest percentage of forest within the Reserve.

- Upland Supratidal Grassland is the third most common habitat for 3 sites: Rachel Carson, Masonboro Island and Zeke's Island. Palustrine Intermittent Scrub-Shrub Broad Leaf Deciduous is present only at Currituck Banks, where it is the third most prevalent habitat.

- Occurrence of habitats is similar between the three southern sites (Rachel Carson, Masonboro Island and Zeke's Island) and different from Currituck Banks. Distribution is strongly influenced by site hydrology. The southern sites have regular lunar tides of the Atlantic Ocean. Currituck Banks is irregularly flooded by wind-driven tides of Currituck Sound. Currituck Banks is the only site with Palustrine Non-tidal Freshwater Wetlands.

- The three southern sites and Currituck Banks are situated, respectively, in the Carolinian and Virginian Biogeographic Provinces. Biogeographic parameters may impact species composition and habitat occurrence. The habitat classification provides a framework for more detailed vegetation inventories and investigation of species distribution.

The NCNERR classified habitats support the following coastal resource management activities:

- Identify sensitive habitats to guide component access, in combination with Visitor Use Surveys.

- Quantify acreages of habitats that are protected within the Reserve. This will support the North Carolina Strategic Conservation Plan, help guide future property acquisition, and ensure that coastal diversity is protected.

- Provide a baseline to assess changes due to natural or anthropogenic effects including sea level rise and climate change.

- Support cross-walk between other classification schemes to understand broader ecosystem classification.

Table 4.3. Habitat Occurrence (% of Site Total of Non-Aquatic Acres)

SYSTEM	SUBSYSTEM - SUBCLASS	Currituck Banks	Rachel Carson	Masonboro Island	Zeke's Island
Cultural Land Cover	CLC Paved Road	0.09			
Cultural Land Cover	CLC Permeable Lot	0.03			
Cultural Land Cover	CLC Rocky In-Water Structure			0.06	0.44
Estuarine	Est. Intertidal Mud				0.21
Estuarine	Est. Intertidal Persistant Wetland		**40.44**	**58.43**	**56.13**
Estuarine	Est. Intertidal Reef Mollusk		0.01		
Estuarine	Est. Intertidal Sand		**30.15**	1.43	3.93
Estuarine	Est. Intertidal Scrub-Shrub BLD			1.81	4.08
Estuarine	Est. Subtidal Organic				0.02
Estuarine	Est. Subtidal Sand			0.30	0.85
Estuarine	Est. Supratidal Persistant Wetland	**17.32**	2.71	4.07	0.77
Estuarine	Est. Supratidal Sand		3.62	3.78	
Estuarine	Est. Supratidal Scrub-Shrub BLD	3.94	3.53	4.74	3.17
Estuarine	Est. Supratidal Scrub-Shrub BLE	2.10	0.13		
Marine	Marine Intertidal Sand	4.42		5.16	3.35
Palustrine	Pal. Intermittent Forest BLD	9.41			
Palustrine	Pal. Intermittent Persistant Wetland	2.12			
Palustrine	Pal. Intermittent Scrub-Shrub BLD	**10.25**			
Palustrine	Pal. Intermittent Scrub-Shrub BLE	6.21			
Upland	Upld. Supratidal Forest BLE	6.52	0.24	0.12	0.02
Upland	Upld. Supratidal Forest Mixed	**11.04**	0.04		
Upland	Upld. Supratidal Forest NLE	2.17			
Upland	Upld. Supratidal Grassland	7.93	**8.43**	**7.64**	**9.96**
Upland	Upld. Supratidal Sand	3.14	3.13	**7.83**	**11.96**
Upland	Upld. Supratidal Scrub-Shrub BLD	5.67	0.22	0.33	1.49
Upland	Upld. Supratidal Scrub-Shrub BLE	7.46	6.82	4.20	4.49
Upland	Upld. Supratidal Scrub-Shrub NLE	0.16	0.27	0.45	
	Habitat Prevalence per Site:	**First**	**Second**	**Third**	

4.2:   Land Cover Methods:

Land Cover conditions are being examined for the watersheds associated with each of the 4 NCNERR components. For this effort, watersheds were defined as US Geologic Survey 8 digit Hydrologic Cataloguing Units, to be compatible with Land Cover information from other NERRs. Synoptic Land Cover data sets were obtained for coastal North Carolina from NOAA's Coastal Change Analysis Program (C-CAP). These data sets are currently available for 1991, 1997 and the changes between the two years. Analysis methods were developed using the Zeke's Island Component and were repeated for the other 3 NCNERR sites. First, each data set (1991, 1997 and 1991 – 1997) was clipped to the geographic extent of the watershed boundary then area distribution of Land Cover Classes and % Total area were calculated. To portray 1991-1997 changes in a meaningful way, the data were combined into 3 categories: 1) Increased Vegetative Cover, 2) Decreased Vegetative Cover and 3) Different Unvegetated Class. The decrease in vegetation cover category includes all areas where the Land Cover changed between 1991 and 1997 to a class that characterizes conditions with generally less plant cover or biomass. Examples of this category are a transition from Forested to Grassland or Scrub-shrub to Low Density Development.   The increase in vegetation cover category was assigned to all areas where the Land Cover changed to a class that represents generally greater plant cover or biomass. Examples of this category are succession of grassland to Scrub-Shrub and Scrub-Shrub to Forested. The change in non-vegetated cover category designates all areas that had different non-vegetated land cover classes in 1991 and 1997. Examples included water to unconsolidated shore, unconsolidated shore to bare land and bare land to low-density developed. Land Cover maps and summaries are presented in the stressors section of the respective chapters for each component.

4.3: Habitat Subclasses found in the NCNERR

1000. Marine Habitats

Marine Intertidal Sand (1243): This subclass represents areas of bare sand between high and low tide lines and is commonly referred to as "The Beach".

2000. Estuarine Habitats

Estuarine Subtidal Sand (2123):
This habitat type is submerged bare sand found in small ponds within areas of higher ground.

Estuarine Subtidal Organic Unconsolidated Bottom (2125):
This habitat type includes organic substrate, not fully exposed at low tide, found beneath small ponds within areas of higher ground.

Estuarine Intertidal Reef Mollusc (2221):
This subclass includes areas of intertidal oyster reefs, found primarily at the Rachel Carson component.

Estuarine Intertidal Sand (2253):
This subclass includes all sandy intertidal (beach) areas not directly touching the Ocean.

Estuarine Intertidal Mud (2254):
These areas, often called "mudflats", represent bare sediments with some organic content. These areas are exposed at low tide and are highly productive feeding grounds for fish at high tide.

Estuarine Intertidal Pesistant Wetland (2261):
This habitat type is known as "Saltmarsh", exposed at low tide, they most often consist of smooth cordgrass (*Spartina alterniflora).*

Estuarine Intertidal Scrub-Shrub Broad Leaf Deciduous (2271):
The intertidal scrub-shrub subclass is dominated by sea ox-eye (*Borrichia frutescens*).

Estuarine Supratidal Persistant Wetland (2341):
This subclass is commonly called the "high marsh". It is made up of salt meadow hay (*Spartina patens*), inland saltgrass (*Distichlis spicata*), and black needle rush (*Juncus roemarianus*).

Estuarine Supratidal Scrub-Shrub Broad Leaf Deciduous (2351):
The subclass is usually adjacent to the intertidal marsh. Dominate plants in this region include: sea ox-eye (*Borrichia frutescens*), salt meadow hay (*Spartina patens)*, sea oats (*Uniola paniculata*), and inland saltgrass (*Distichlis spicata*).

Estuarine Supratidal Scrub-Shrub Broad Leaf Evergreen (2353):
This subclass includes short woody (< 20 ft) vegetation including wax myrtle (*Myrica cerifera*), holly (*Ilex cassine*) and Sweet Bay (*Magnolia viginiana*).

5000. Palustrine Habitats

Palustrine Intermittant Persistent Wetland (5232):
This subclass represents areas that are irregularly saturated with fresh water with the predominant vegetation being saltmeadow cordgrass (*Spartina patens*).

Palustrine Intermittant Scrub-Shrub Broad Leaf Deciduous (5241):
This subclass includes immature or stunted (<20 ft) forms of woody vegetation including Red Maple (*Acer rubrum),* Carolina Willow (*Salix caroliniana*), Willow Oak (*Quercus phellos*), Persimmon *(Diospyros viginiana*) and Black Gum (*Nyssa sylvatica*).

Palustrine Intermittant Scrub-Shrub Broad Leaf Evergreen (5243):
This subclass represents communities of mixed vegetation (<20 ft) that include live oak (*Quercus virginiana*), yaupon (*Ilex vomitoria*), wax myrtle (*Morella cerifera* or *Myrica cerifera*), and laurel oak (*Quercus laurifolia*).

Palustrine Intermittant Forest Broad Leaf Deciduous (5251):
These are areas of mature forest (>20 ft) with species that include Red Maple (*Acer rubrum),* Carolina Willow (*Salix caroliniana*), Willow Oak (*Quercus phellos*), Persimmon *(Diospyros viginiana*) and Black Gum (*Nyssa sylvatica*)

6000. Upland Habitats

Upland Supratidal Sand (6123):
These are areas of upland sand, with less than 30% vegetative cover.

Upland Supratidal Grassland (6131):
These grassland areas are inhabited by a mixed community of perennial beach grasses such as salt meadow hay (*Spartina patens)*, sea oats (*Uniola paniculata*), inland saltgrass (*Distichlis spicata*) and various species of *Panicum.*

Upland Supratidal Scrub-Shrub Broad Leaf Deciduous (6141):
This is a mixed community of shrub species, often referred to as "shrub thicket". Example species are marsh elder (*Iva frutescens*), and grounsel tree (*Baccharis halimifolia*).

Upland Supratidal Scrub-Shrub Broad Leaf Evergreen (6143):
The woody vegetation represented by this subclass is <20ft in height, with a mix of yaupon (*Ilex vomitoria*), wax myrtle (*Morella cerifera* or *Myrica cerifera*), laurel oak (*Quercus laurifolia*).

Upland Supratidal Scrub-Shrub Needle Leaf Evergreen (6144):
This subclass includes needle leaf shrubs (<20 ft), predominantly eastern red cedar (*Juniperus virginiana*).

Upland Supratidal Forest Broad Leaf Evergreen (6153):
This subclass is represented by stands of mature trees, greater than 20 ft in height. Species include live oak (*Quercus virginiana*), yaupon (*Ilex vomitoria*), wax myrtle (*Morella cerifera* or *Myrica cerifera*), and laurel oak (*Quercus laurifolia*).

Upland Supratidal Forest Needle Leaf Evergreen (6154):
This subclass is composed primarily of loblolly pines (*Pinus taeda*) with a small unique stand of longleaf pine (*Pinus palustris*) found at Currituck Banks.

Upland Supratidal Forest Mixed (6155):
This subclass includes a mix of mature trees, with no species occupying >75% of the community. Species may include loblolly pines (*Pinus taeda*) and broad leaf trees, including live oak (*Quercus virginiana)*, yaupon (*Ilex vomitoria*), wax myrtle (*Morella cerifera)*.

8000. Cultural Land Cover Habitats

Cultural Land Cover Rocky In Water Structures (8342):
This subclass refers to the rock wall jetties that surround the basin area at Zeke's Island, and protect Masonboro Inlet.

4.5: References

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4.6: NERR Habitat Classification Scheme (June 2006)

- 1000. Marine Habitats System
  - 1100. Subtidal
    - 1110. Rock Bottom
      - 1111. Bedrock
      - 1112. Rubble
    - 1120. Unconsolidated Bottom
      - 1121. Cobble
      - 1122. Gravel
      - 1123. Sand
      - 1124. Mud
      - 1125. Organic
    - 1130. Aquatic Bed
      - 1131. Rooted Algal
      - 1132. Drift Algal
      - 1133. Rooted Vascular
      - 134. Faunal
    - 1140. Reef
      - 1141. Mollusk
      - 1142. Coral
      - 1143. Worm
      - 1144. Artificial
  - 1200. Intertidal
    - 1210. Aquatic Bed
      - 1211. Rooted Algal
      - 1212. Drift Algal
      - 1213. Rooted Vascular
    - 1220. Reef
      - 1221. Coral
      - 1222. Worm
    - 1230. Rocky Shore
      - 1231. Bedrock
      - 1232. Rubble
    - 1240. Unconsolidated Shore
      - 1241. Cobble
      - 1242. Gravel
      - 1243. Sand
      - 1244. Mud
      - 1245. Organic
- 2000. Estuarine Habitats
  - 2100. Subtidal Haline
    - 2110. Rock Bottom
      - 2111. Bedrock
      - 2112. Rubble
    - 2120. Unconsolidated Bottom
      - 2121. Cobble

- 2122. Gravel
- 2123. Sand
- 2124. Mud
- 2125. Organic

2130. Aquatic Bed
- 2131. Rooted Algal
- 2132. Drift Algal
- 2133. Rooted Vascular
- 2134. Floating Vascular
- 2135. Faunal

2140. Reef
- 2141. Mollusk
- 2142. Worm
- 2143. Artificial

2200. Intertidal Haline

2210. Aquatic Bed
- 2211. Rooted Algal
- 2212. Drift Algal
- 2213. Rooted Vascular
- 2214. Floating Vascular

2220. Reef
- 2221. Mollusk
- 2222. Worm

2230. Streambed
- 2231. Bedrock
- 2232. Rubble
- 2233. Cobble
- 2234. Gravel
- 2235. Sand
- 2236. Mud
- 2337. Organic

2240. Rocky Shore
- 2241. Bedrock
- 2242. Rubble

2250. Unconsolidated Shore
- 2251. Cobble
- 2252. Gravel
- 2253. Sand
- 2254. Mud
- 2255. Organic

2260. Emergent Wetland
- 2261. Persistent
- 2262. Nonpersistent

2270. Scrub-Shrub Wetland
- 2271. BLD
- 2272. NLD

- 2273. BLE
- 2274. NLE
- 2275. Dead
- 2280. Forested Wetland
  - 2281. BLD
  - 2282. NLD
  - 2283. BLE
  - 2284. NLE
  - 2285. Mixed
  - 2286. Dead
- 2300. Supratidal Haline
  - 2310. Rock Bottom
    - 2311. Bedrock
    - 2312. Rubble
  - 2320. Unconsolidated Bottom
    - 2321. Cobble
    - 2322. Gravel
    - 2323. Sand
    - 2324. Mud
    - 2325. Organic
  - 2330. Aquatic Bed
    - 2331. Rooted Algal
    - 2332. Drift Algal
    - 2333. Rooted Vascular
    - 2334. Floating Vascular
  - 2340. Emergent Wetland
    - 2341. Persistent
    - 2342. Nonpersistent
  - 2350. Scrub-Shrub Wetland
    - 2351. BLD
    - 2352. NLD
    - 2353. BLE
    - 2354. NLE
    - 2355. Dead
  - 2360. Forested Wetland
    - 2361. BLD
    - 2362. NLD
    - 2363. BLE
    - 2364. NLE
    - 2365. Mixed
    - 2366. Dead
- 2400. Subtidal Fresh
  - 2410. Rock Bottom
    - 2411. Bedrock
    - 2412. Rubble
  - 2420. Unconsolidated Bottom

- 2421. Cobble
- 2422. Gravel
- 2423. Sand
- 2424. Mud
- 2425. Organic

2430. Aquatic Bed
- 2431. Rooted Algal
- 2432. Drift Algal
- 2433. Rooted Vascular
- 2434. Floating Vascular
- 2435. Aquatic Moss

2440. Reef
- 2441. Mollusk

2500. Intertidal Fresh

2510. Aquatic Bed
- 2511. Rooted Algal
- 2512. Drift Algal
- 2513. Rooted Vascular
- 2514. Floating Vascular
- 2515. Aquatic Moss

2520. Streambed
- 2521. Bedrock
- 2522. Rubble
- 2523. Cobble
- 2524. Gravel
- 2525. Sand
- 2526. Mud
- 2527. Organic

2530. Rocky Shore
- 2531. Bedrock
- 2532. Rubble

2540. Unconsolidated Shore
- 2541. Cobble
- 2542. Gravel
- 2543. Sand
- 2544. Mud
- 2545. Organic

2550. Emergent Wetland
- 2551. Persistent
- 2552. Nonpersistent

2560. Scrub-Shrub Wetland
- 2561. BLD
- 2562. NLD
- 2563. BLE
- 2564. NLE
- 2565. Dead

- 2570. Forested Wetland
  - 2571. BLD
  - 2572. NLD
  - 2573. BLE
  - 2574. NLE
  - 2575. Mixed
  - 2575. Dead

3000. Riverine Habitats
- 3100. Lower Perennial
  - 3110. Unconsolidated Bottom
    - 3111. Gravel
    - 3112. Sand
    - 3113. Mud
    - 3114. Organic
  - 3120. Aquatic Bed
    - 3121. Aquatic Moss
    - 3122. Rooted Vascular
    - 3123. Floating Vascular
  - 3130. Rocky Shore
    - 3131. Bedrock
    - 3132. Rubble
  - 3140. Unconsolidated Shore
    - 3141. Cobble
    - 3142. Gravel
    - 3143. Sand
    - 3144. Mud
    - 3145. Organic
  - 3150. Emergent Wetland
    - 3151. Nonpersistent
- 3200. Upper Perennial
  - 3210. Rock Bottom
    - 3211. Bedrock
    - 3212. Rubble
  - 3220. Unconsolidated Bottom
    - 3221. Cobble
    - 3222. Gravel
    - 3223. Sand
    - 3224. Mud
  - 3230. Aquatic Bed
    - 3231. Algal
    - 3232. Aquatic Moss
    - 3233. Rooted Vascular
    - 3234. Floating Vascular
  - 3240. Rocky Shore
    - 3241. Bedrock
    - 3242. Rubble

- 3250. Unconsolidated Shore
  - 3251. Cobble
  - 3252. Gravel
  - 3253. Sand
  - 3254. Mud
  - 3255. Organic
- 3260. Emergent Wetland
  - 3261. Nonpersistent

3300. Intermittent
- 3310. Streambed
  - 3311. Bedrock
  - 3312. Rubble
  - 3313. Cobble
  - 3314. Gravel
  - 3315. Sand
  - 3316. Mud
  - 3317. Organic
  - 3318. Vegetated

4000. Lacustrine Habitats
- 4100. Limnetic
  - 4110. Rock Bottom
    - 4111. Bedrock
    - 4112. Rubble
  - 4120. Unconsolidated bottom
    - 4121. Cobble
    - 4122. Gravel
    - 4123. Sand
    - 4124. Mud
    - 4125. Organic
  - 4130. Aquatic Bed
    - 4131. Algal
    - 4132. Aquatic Moss
    - 4133. Rooted Vascular
    - 4134. Floating Vascular
- 4200. Littoral
  - 4210. Rock Bottom
    - 4211. Bedrock
    - 4212. Rubble
  - 4220. Unconsolidated Bottom
    - 4221. Cobble
    - 4222. Gravel
    - 4223. Sand
    - 4224. Mud
    - 4225. Organic
  - 4230. Aquatic Bed
    - 4231. Algal

- 4232. Aquatic Moss
- 4233. Rooted Vascular
- 4234. Floating vascular
- 4240. Rocky Shore
  - 4241. Bedrock
  - 4242. Rubble
- 4250. Unconsolidated Shore
  - 4251. Cobble
  - 4252. Gravel
  - 4253. Sand
  - 4254. Mud
  - 4255. Organic
- 4260. Emergent Wetland
  - 4261. Nonpersistent
- 5000. Palustrine Habitats
  - 5100. Perennial Water
    - 5110. Rock Bottom
      - 5111. Bedrock
      - 5112. Rubble
    - 5120. Unconsolidated Bottom
      - 5121. Cobble
      - 5122. Gravel
      - 5123. Sand
      - 5124. Mud
      - 5125. Organic
    - 5130. Aquatic Bed
      - 5131. Algal
      - 5132. Aquatic Moss
      - 5133. Rooted Vascular
      - 5134. Floating vascular
    - 5140. Emergent Wetland
      - 5141. Nonpersistent
  - 5200. Intermittent or Saturated
    - 5210. Unconsolidated Shore
      - 5211. Cobble
      - 5212. Gravel
      - 5213. Sand
      - 5214. Mud
      - 5215. Organic
    - 5220. Moss-Lichen Wetland
      - 5221. Moss
      - 5222. Lichen
    - 5230. Emergent Wetland
      - 5231. Nonpersistent
      - 5232. Persistent
    - 5240. Scrub-Shrub Wetland

5241. BLD
5242. NLD
5243. BLE
5244. NLE
245. Dead
5250. Forested Wetland
5251. BLD
5252. NLD
5253. BLE
5254. NLE
5255. Mixed
5256. Dead
6000. Upland Habitats
6100. Supratidal Upland
6110. Rocky Upland
6111. Bedrock
6112. Rubble
6120. Unconsolidated Upland
6121. Cobble
6122. Gravel
6123. Sand
6124. Clay
6125. Loam
6126. Organic
6130. Herbaceous Upland
6131. Grassland
6132. Broad-leaved Herbs
6140. Scrub-Shrub Upland
6141. BLD
6142. NLD
6143. BLE
6144. NLE
6145. Dead
6150. Forested Upland
6151. BLD
6152. NLD
6153. BLE
6154. NLE
6155. Mixed
6156. Dead
6200. Inland Upland
6210. Rocky Upland
6211. Bedrock
6212. Rubble
6220. Unconsolidated Upland
6221. Cobble

- 6222. Gravel
- 6223. Sand
- 6224. Clay
- 6225. Loam
- 6226. Organic
- 6230. Herbaceous Upland
  - 6231. Grassland
  - 6232. Broad-leaved Herbs
- 6240. Scrub-Shrub Upland
  - 6241. BLD
  - 6242. NLD
  - 6243. BLE
  - 6244. NLE
  - 6245. Dead
- 6250. Forested Upland
  - 6251. BLD
  - 6252. NLD
  - 6253. BLE
  - 6254. NLE
  - 6255. Mixed
  - 6256. Dead

7000. Perennial Snow and Ice Habitats
- 7100. Perennial Snowfields
- 7200. Glaciers

8000. Cultural Land Cover
- 8100. Developed Upland
  - 8110. Impervious Cover
    - 8111. Paved Lot
    - 8112. Paved Roadway
    - 8113. Large Building
    - 8114. Impervious Complex
  - 8120. Built-up Cover
    - 8121. Commercial or Service Complex
    - 8122. Industrial Complex
  - 8130. Residential Cover
    - 8131. Low Density
    - 8132. Medium Density
    - 8133. High Density
  - 8140. Rocky Cover
    - 8141. Rocky Revetment
    - 8142. Open Quarry
  - 8150. Unconsolidated Cover
    - 8151. Cleared Land
    - 8151. Dirt Lot
    - 8152. Gravel Road
    - 8153. Railway Corridor

- 8154. Mining Operation
- 8155. Landfill Operation
- 8160. Herbaceous Cover
  - 8161. Managed Turf
  - 8162. Managed Garden
  - 8163. Managed Old Field
- 8170. Shrub Cover
  - 8171. Managed Shrubs
- 8180. Tree Cover
  - 8181. Managed Trees
- 8200. Agricultural Upland
  - 8210. Rocky Cover
    - 8211. Rocky Revetment
  - 8220. Unconsolidated Cover
    - 8221. Unvegetated Farmland
  - 8230. Herbaceous Cover
    - 8231. Turf
    - 8232. Pasture
    - 8233. Hay Meadow
    - 8234. Crops/Cover Crops
  - 8240. Shrub Cover
    - 8241. Shrub Nursery
    - 8242. Shrub Rangeland
  - 8250. Tree Cover
    - 8251. Tree Farm
    - 8252. Orchard
    - 8253. Wooded Rangeland
- 8300. Developed and Managed Wetlands and Water
  - 8310. Impervious Cover
    - 8311. Impervious Bottom
    - 8312. Impervious In-water Structure
  - 8320. Built-up Cover
    - 8321. Pervious In-water Structure
    - 8322. In-water Commercial or Service Complex
    - 8323. In-water Industrial Complex
    - 8324. Shellfish Aquiculture
    - 8325. Finfish Aquiculture
  - 8330. Residential Cover
    - 8331. In-water Residential Complex
  - 8340. Rocky Cover
    - 8341. Rocky Shoreline Structure
    - 8342. Rocky In-water Structure
  - 8350. Unconsolidated Cover
    - 8351. Managed Unconsolidated Bottom
    - 8352. Managed Unconsolidated Shore
  - 8360. Herbaceous Cover

- 8361. Managed Herbaceous Wetland
- 8362. Agricultural Herbaceous Wetland
- 8363. Grazed Herbaceous Wetland

8370. Shrub Cover
- 8371. Managed Wetland Shrubs
- 8372. Agricultural Wetland Shrubs
- 8373. Grazed Shrub Wetland

8380. Tree Cover
- 8381. Managed Wetland Trees
- 8382. Agricultural Wetland Trees
- 8383. Grazed Wooded Wetland

Appendix 5: NCNERR Species List

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Group: Birds	
Common Name	**Scientific Name**
American avocet	*Recurvirostra americana*
American bittern	*Botaurus lentiginosus*
American black duck	*Anas rubripes*
American coot	*Fulica americana*
American crow	*Corvus brachyrhynchos*
American flycatcher	*Empldonaxs alvinii*
American goldenfinch	*Carduelis tristis*
American golden plover	*Pluvialis dominica*
American kestrel	*Falco sparverius*
American oystercatcher	*Haematopus palliates*
American pipit	*Anthus spinoletta*
American redstart	*Setophaga ruticilla*
Amercian robin	*Turdus migratorius*
American white pelican	*Pelecanus erythrorhynchos*
American wigeon	*Anas americana*
American woodcock	*Philohela minor*
Audubon's shearwater	*Puffinus iherminieri*
Bald eagle	*Haliaeetus leucocephalus*
Baltimore oriole	*Icterus galbula*
Bank swallow	*Riparia riparia*
Barn owl	*Tyto alba*
Barn swallow	*Hirundo rustica*
Bay breasted warbler	*Dendroica castanea*
Belted kingfisher	*Megaceryle alcyon*
Black rail	*Laterallus jamaicensis*
Black guilliemot	*Cepphus grylle*
Black scoter	*Melanitta nigra*
Black skimmer	*Rynchops niger*
Black tern	*Chlidonias niger*

Group: Birds	
Common Name	**Scientific Name**
Black vulture	*Coragyps atratus*
Black-and-white warbler	*Mniotilta varia*
Black-bellied plover	*Pluvialis squatarola*
Black-billed cuckoo	*Coccyzus erythropthalmus*
Black-crowned night heron	*Nycticorax nycticorax*
Blackburnian warbler	*Dendroica fusca*
Blackpoll warbler	*Dendroica striata*
Black legged kittiwake	*Rissa tridactyla*
Black-throated blue warbler	*Dendroica caerulescens*
Black-throated green warbler	*Dendroica virens*
Blue goose	*Chen cairulescns*
Blue grosbeak	*Guiraca caerulea*
Blue jay	*Cyanocitta cristata*
Blue-gray gnatcatcher	*Polioptila caerulea*
Blue-headed vireo	*Vireo solitarius*
Blue-winged teal	*Anas discors*
Blue-winged warbler	*Vermivora pinus*
Boat-tailed grackle	*Quiscalus major*
Bobolink	*Dolichonyx oryzivorus*
Bonaparte’s gull	*Larus philadelphia*
Brant	*Branta bernicla*
Bridled tern	*Sterna anaethetus*
Broad-winged hawk	*Buteo platypterus*
Brown creeper	*Certhia americana*
Brown headed cowbird	*Molothrus ater*
Brown headed nuthatch	*Sitta pusilla*
Brown noddy	*Anous stolidus*
Brown pelican	*Pelecanus occidentalis*

Appendix 5: NCNERR Species List

Group: Birds	
Common Name	**Scientific Name**
Brown thrasher	*Toxostoma rufum*
Bufflehead	*Bucephala albeola*
Canada goose	*Branta canadensis*
Canadian warbler	*Wilsonia canadensis*
Canvasback	*Aythya valisineria*
Cape may warbler	*Dendroica tigrina*
Carolina chickadee	*Parus carolinensis*
Carolina wren	*Thryothorus ludovicianus*
Caspian tern	*Sterna caspia*
Cattle egret	*Bubulcus ibis*
Cedar waxwing	*Bombycilla cedrorum*
Chestnut-sided warbler	*Dendroica pensylvanica*
Chimney swift	*Chaitura pelagica*
Chipping sparrow	*Spizella passerina*
Chuck-will's-widow	*Caprimulgus carolinensis*
Clapper rail	*Rallus longirostris*
Clay-colored sparrow	*Spizella pallida*
Cliff swallow	*Petrochelidon pyrrhonota*
Common goldeneye	*Bucephala clangula*
Common eider	*Somateria mollissima*
Common grackle	*Quiscalus quiscula*
Common ground-dove	*Columbina passerina*
Common loon	*Gavial immer*
Common merganser	*Mergus merganser*
Common moorhen	*Gallinula chloropus*
Common nighthawk	*Chordeiles minor*
Common redpoll	*Carduelis flammea*
Common snipe	*Capella gallinago*
Common tern	*Sterna hirundo*
Common yellowthroat	*Geothlypis trichas*

Group: Birds	
Common Name	**Scientific Name**
Connecticul warbler	*Oporornis agilis*
Cooper's hawk	*Accipiter cooperii*
Cory's shearwater	*Puffinus diomedea*
Curlew sanpiper	*Calidris ferruginea*
Dark-eyed junco	*Junco hyemalis*
Dickcissel	*Spiza Americana*
Double-crested cormorant	*Phalacrocorax auritus*
Dovekie	*Alle alle*
Downy woodpecker	*Picoides pubescens*
Dunlin	*Calidris alpine*
Eared grebe	*Podiceps nigricollis*
Eastern bluebird	*Sialia sialis*
Eastern kingbird	*Tyrannus tyrannus*
Eastern meadowlark	*Sturnella magna*
Eastern phoebe	*Sayornis phoebe*
Eastern screech owl	*Otus asio*
Eastern towhee	*Pipilo erthrophthalmus*
Eastern wood-pewee	*Contupus virens*
Empidonax, spp	Empidonax, spp
Eurasian collared-dove	*Streptopelia decaocto*
European starling	*Sturnus vulgaris*
Evening grosbeak	*Hesperiphona vestertina*
Field sparrow	*Spizella pusilla*
Fish crow	*Corvus ossifragus*
Forster's tern	*Sterna forsteri*
Fox sparrow	*Passerella iliaca*
Franklin's gull	*Larus pipizcan*
Gadwall	*Anas strepera*
Glaucous gull	*Larus hyperboreus*
Glossy ibis	*Plegadis falcinellus*

Appendix 5: NCNERR Species List

Group: Birds	
Common Name	**Scientific Name**
Golden plover	*Pluvialis dominica*
Golden winged warbler	*Vermivora chrysopter*
Golden-crowned kinglet	*Regulus satrapa*
Grasshopper sparrow	*Ammodramus savannarum*
Gray catbird	*Dumetella carolinensis*
Gray kingbird	*Tyrannus dominicensis*
Gray-cheeked thrush	*Catharus minimus*
Great black-backed gull	*Larus marinus*
Great blue heron	*Ardea herodias*
Great cormorant	*Phalacrocorax carbo*
Great crested flycatcher	*Myiarchus crinitus*
Great egret	*Casmerodius albus*
Great horned owl	*Bubo virginianus*
Greater scaup	*Aythya marila*
Greater shearwater	*Puffinus gravis*
Greater yellowlegs	*Tringa melanoleuca*
Green heron	*Butorides striatus*
Green-winged teal	*Anas crecca*
Gull-billed tern	*Gelochelidon nilotica*
Harlequin duck	*Histrionicus histrionicus*
Hermit thrush	*Catharus guttatus*
Herring gull	*Larus argentatus*
Hooded merganser	*Lophodytes cucullatus*
Hooded warbler	*Wilsonia citrina*
Horned grebe	*Podiceps auritus*
Horned lark	*Eremophila alpestris*
House finch	*Carpodacus mexicanus*
House sparrow	*Passer domesticus*
House wren	*Troglodytes aedon*
Hudsonian godwit	*Limosa haemastica*

Group: Birds	
Common Name	**Scientific Name**
Iceland gull	*Larus glaucoides*
Indigo bunting	*Passerina cyanea*
Kentucky warbler	*Oporornis aglis*
Killdeer	*Charadrius vociferous*
King eider	*Somateria spectabilis*
King rail	*Rallus elegans*
Lapland longspur	*Calcarius lapponicus*
Lark sparrow	*Chondestes grammacus*
Laughing gull	*Larus atricilla*
Least bittern	*Ixobrychus exilis*
Least flycatcher	*Empidonaz minimus*
Least sandpiper	*Calidris minutilla*
Least tern	*Sterna albifrons*
Lesser black-backed gull	*Larus fuscus*
Lesser scaup	*Aythya affinis*
Lesser yellowlegs	*Tringa flavipes*
Little blue heron	*Florida caerulea*
Little gull	*Larus minutus*
Lincoln's sparrow	*Melospiza lincolnii*
Loggerhead shrike	*Lanius ludovicianus*
Long-billed curlew	*Numenius americanus*
Long-billed dowitcher	*Limnodromus scolopaceus*
Long-tailed duck	*Clangula hyemalis*
Magnificent frigatebird	*Fregata magnificens*
Magnolia warbler	*Dendroica magnolia*
Mallard	*Anas platyrhynchos*
Marbled godwit	*Limosa fedoa*
Marsh wren	*Cistothorus palustris*
Masked booby	*Sula dactylatra*
Merlin	*Falco columbarius*

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Group: Birds	
Common Name	**Scientific Name**
Mississippe kite	*Ictinia mississipiensis*
Mourning dove	*Zenaida macroura*
Mourning warbler	*Oporornis philadelphia*
Mute swan	*Cygnus olor*
Narshville warbler	*Vermivora ruficapilla*
Nelson's sharp-tailed	*Ammodramus nelsoni*
N. rough-winged swallow	*Stelgidopteryx ruficollis*
Northern bobwhite	*Colinus virginianus*
Northern cardinal	*Cardinalis cardinalis*
Northern flicker	*Colaptes auratus*
Northern gannet	*Morus bassanus*
Northern harrier	*Circus cyaneus*
Northern mockingbird	*Mimus polyglottos*
Northern parula	*Parula americana*
Northern pintail	*Anas acuta*
Northern saw-whet owl	*Aegolius acadicus*
Northern shoveler	*Anas clypeata*
Northern waterthrush	*Seiurus noveboracensis*
Oldsquaw	*Clangula hyemalis*
Orange-crowned warbler	*Vermivora celata*
Orchard oriole	*Icterus spurius*
Osprey	*Pandion haliaetus*
Ovenbird	*Seiurus aurocapillus*
Painted bunting	*Passerina ciris*
Palm warbler	*Dendroica palmarum*
Parastic jaeger	*Stercorarius parasiticus*
Pectoral sandpiper	*Calidris melnotos*
Peregrine falcon	*Falco peregrinus*
Philadelphia vireo	*Vireo philadelphicus*
Pied-billed grebe	*Podilymbus podiceps*

Group: Birds	
Common Name	**Scientific Name**
Pileated woodpecker	*Dryocopus pileatus*
Pine siskin	*Carduelis pinus*
Pine warbler	*Dendroica pinus*
Piping plover	*Charadrius melodus*
Pomarine jaeger	*Stercorarius pomarinus*
Prairie warbler	*Dendroica discolor*
Prothonotary warbler	*Protonotaria citrea*
Purple finch	*Carpodacus purpureus*
Purple gallinule	*Porphurula martinica*
Purple martin	*Progne subis*
Purple sandpiper	*Calidris maritima*
Razorbill	*Alca torda*
Red knot	*Calidris canutus*
Red phalarope	*Phalaropus fulicarius*
Red-bellied woodpecker	*Melanerpes carolinus*
Red-breasted merganser	*Mergus serrator*
Red-breasted nuthatch	*Sitta canadensis*
Red-eyed vireo	*Vireo olivaceus*
Redhead	*Aythya americana*
Redish egret	*Dichromanassa rufescens*
Red-headed woodpecker	*Melanerpes erthrocehpalus*
Red-necked grebe	*Poduceps grisegena*
Red-necked phalarope	*Phalaropus fulicarius*
Red--shouldered hawk	*Buteo lineatus*
Red-winged blackbird	*Agelaius phoeniceus*
Red-tailed hawk	*Buteo jamaicensis*
Red-throated loon	*Gavia stellata*
Ring-billed gull	*Larus delawarensis*
Ring-necked duck	*Aythya collarus*
Rock dove	*Columba livia*

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Group: Birds	
Common Name	**Scientific Name**
Rose-breasted grosbeak	*Pheucticus ludovicianus*
Roseate spoonbill	*Ajaia ajaja*
Royal tern	*Sterna maxima*
Ruby-crowned kinglet	*Regulus calendula*
Ruby-throated hummingbird	*Archilochus colubris*
Ruddy duck	*Oxyura jamaicensis*
Ruddy turnstone	*Arenaria interpres*
Rufous-sided towhee	*Pipila erythrophthalmus*
Rusty blackbird	*Euphagus carolinus*
Saltmarsh sharp-tailed	*Ammodramus cauducutus*
Sanderling	*Calidris alba*
Sandwich tern	*Sterna sandvicensis*
Savannal sparrow	*Passerculus sandwichensis*
Scarlet tanger	*Piranga olivacea*
Seaside sparrow	*Ammospiza maritime*
Sedge wren	*Cistothorus platensis*
Semipalmated plover	*Charadrius semipalmatus*
Semipalmated sandpiper	*Calidris pusilla*
Sharp-shinned hawk	*Accipiter striatus*
Shiny cowbird	*Molothrus bonariensis*
Short-billed dowitcher	*Limnodromus griseus*
Short-eared owl	*Asio flammeus*
Snow bunting	*Plectrophenax nivalis*
Snow goose	*Chen caerulescens*
Snowy owl	*Nyctea scandiaca*
Snowy egret	*Egretta thula*
Solitary sandpiper	*Tringa solitaria*
Song sparrow	*Melospiza melodia*
Sora	*Porzana carolina*
Sooty shearwater	*Puffinus griseus*

Group: Birds	
Common Name	**Scientific Name**
Sooty tern	*Sterna fuscata*
Spotted sandpiper	*Actitis macularia*
Stilt sandpiper	*Micropalama himantopus*
Summer tanger	*Piranga rubra*
Surf scoter	*Melanitta perspicillata*
Swainson's thrush	*Catharus ustulatus*
Swallow-tailed kite	*Elanoides forficatus*
Swamp sparrow	*Melispiza georgiana*
Tennessee warbler	*Vermivora peregrina*
Thick-billed murre	*Uria lomvia*
Tree swallow	*Iridoprocne bicolor*
Tricolored heron	*Hydranassa tricolor*
Tufted titmouse	*Parus bicolor*
Tundra swan	*Cygnus columbianus*
Turkey vulture	*Cathartes aura*
Upland sandpiper	*Bartramia longicauda*
Veery	*Catharus fuscenscens*
Vesper sparrow	*Pooecetes gramineus*
Virginia rail	*Rallus limicola*
Western kingbird	*Tyrannus verticalis*
Western sandpiper	*Calidris mauri*
Whimbrel	*Numenius phaeopus*
Whip-poorwill	*Caprimulgus vociferus*
White ibis	*Eudocimus albus*
White-crowned sparrow	*Zonotrichia leucophrys*
White-eyed vireo	*Vireo griseus*
White-rumped sandpiper	*Calidris fuscicollis*
White-tailed kite	*Elanus leucurus*
White-throated sparrow	*Zonotrichia albicollis*
White-winged scoter	*Melanitta deglandi*

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Group: Birds	
Common Name	**Scientific Name**
Willet	*Catoptrophorus semipalmatus*
Willow-alder flycatcher	*Empidonaz alnorum*
Wilson's thalarope	*Steganopus tricolor*
Wilson's plover	*Charadrius alexandrinus*
Wilson's storm-tetrel	*Oceanites oceanicus*
Wilson's warbler	*Wilsonia pusilla*
Winter wren	*Troglodytes troglodytes*
Wood duck	*Aix sponsa*
Wood thrush	*Hylocichla mustelina*
Worm-eating warlbler	*Helmitheros vermivorus*
Yellow-bellied flycatcher	*Empidonaz flaviventris*
Yellow-billed cuckoo	*Coccuzus americanus*
Yellow crowned night heron	*Nyctanassa violacea*
Yellow-headed blackbird	*Xanthocehalus xanthocephalus*
Yellow warbler	*Dendroica petechia*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Yellow-breasted chat	*Icteria virens*
Yellow-rumped warbler	*Dendroica coronata*
Yellow-throated vireo	*Vireo flavifrons*
Yellow-throated warbler	*Dendroica dominica*

Group: Mammals	
Common Name	**Scientific Name**
Feral horse	*Equus caballus*
Raccoon	*Procyon lotor*
Nutria	*Myocastor coypus*
Virginia opossum	*Didelphis virginiana*
Atlantic bottle-nose dolphin	*Tursiops truncatus*
Meadow mouse	*Microtus pennsylvanica*

Group: Mammals	
Common Name	**Scientific Name**
Cotton mouse	*Peromyscus gossypinus*
White-tailed deer	*Odocoileus virginianus*
River otter	*Lutra canadensis*
Marsh rabbit	*Sylvilagus palustris*
Eastern cottontail rabbit	*Sylvilagus floridanus*
Short-tailed shrew	*Blarina brevicauda*
Eastern mole	*Scalopus aquaticus*
Big brown bat	*Eptesicus fuscus*
Gray squirrel	*Sciurus carolinensis*
Fox squirrel	*Sciurus niger*
Muskrat	*Ondontra*
Red fox	*Vulpes vulpes*
Gray fox	*Urocyon cinereoargenteas*
Harbor seal	*Phoca vitulina*
Harbor porpoise	*Phocoena phocoena*
House mouse	*Mus musculus*
Norway rat	*Rattus norvegicus*
Mink	*Mustela vison*
Hispid cotton rat	*Sigmondon hispidus*
Marsh rice rat	*Oryzomys palustris*
Least shrew	*Cryptotis parva*
Red bat	*Lasiurus borealis*
Seminole bat	*Lasiurus seminolus*
Manatee	*Trichechus manatus*
Eastern harvest mouse	*Reithrodontomys humilis*
White-footed mouse	*Peromyscus leocopus*
Marsh rice rat	*Oryzomys palustris*
Norway rat	*Rattus norvegicus*
Least shrew	*Crytotis parva*
Southerneastern shrew	*Sorex longerosytris*

Appendix 5: NCNERR Species List

Group: Mammals	
Common Name	**Scientific Name**
Meadow vole	*Microtus pennsylvanicus*

Group: Reptiles	
Common Name	**Scientific Name**
Alligator	*Alligator mississippiensis*
Atlantic loggerhead	*Caretta caretta caretta*
Black rat snake	*Elaphe □olyploi obsoleta*
Bog turtle	*Clemmys muhlenbergii*
Broad-headed skink	*Eumeces laticeps*
Brown water snake	*Natrix taxispilota*
Carolina pygmy rattlesnake	*Sistrurus miliarius miliarius*
Carolina watersnake	*Nerodia sipedon williamengelsi*
Chicken turtle	*Deirochelys reticularia*
Coastal Plain milk snake	*Lampropeltis triangulum*
Common watersnake	*Nerodia sipedon sipedon*
Corn snake	*Elaphe guttata guttata*
Eastern box turtle	*Terrapeme □olyploi carolina*
Eastern coachwhip	*Masticophis flagellum flagellum*
Eastern cottonmouth	*Agkistrodon piscivorus*
Eastern diamond-backed tattlesnake	*Crotalus adamanteus*
Eastern garter snake	*Thamnophis sirtalis sirtalis*
Eastern glass lizard	*Ophisaurus ventralis*
Eastern hognose snake	*Heterdon platyrhinos*
Eastern king snake	*Lampropeltis getulus getulus*
Eastern milksnake	*L. triangulum triangulum*
Eastern mud snake	*Farancia abacura abacura*
Eastern mud turtle	*Kinosternon subrubrum subrubrum*
Eastern musk turtle stinkpot	*Sternotherus odoratus*
Eastern painted turtle	*Chrysemys picta picta*

Group: Reptiles	
Common Name	**Scientific Name**
Eastern ribbon snake	*Thamnophis sauritus sauritus*
Eastern smooth earth snake	*Virginia valeriae*
Eastern wood snake	*Carphophis amoenus amoenus*
Fence lizard	*Sceloporus □olyploid hyacinthinus*
Five-lined skink	*Eumeces fasciatus*
Florida cooter	*Chrysemys floridana floridana*
Green anole (Carolina anole)	*Anolis carolinensis*
Green sea turtle	*Chelonia mydas*
Ground skink	*Leiolopisma laterale*
Leatherback sea turtle	*Dermochelys coriacea*
Little brown skink	*Scincella lateralis*
Mimic glass lizard	*Ophisaurus mimicus*
Northern black racer	*Coluber constrictor constrictor*
Northern brown snake	*Storeria dekayi dekayi*
Northern diamondback terrapin	*malaclemys terrapin terrapin*
Northern scarlet snake	*Cemophora coccinea copei*
Nothern water snake	*Natrix sipedon sipedon*
Pine woods snake	*Rhadinae flavilata*
Rainbow snake	*Farancia erythrogram*
Red bellied cooter	*Pseudemys rubriventris*
Red-bellied snake	*Storeria occipitomaculata*
Red-bellied turtle	*Chrysemys rubiventris*
Red-bellied watersnake	*Nerodia erythrogaster erythrogaster*
Red-eared slider	*T. scripta elegans*
Rough earth snake	*Virginia striatulla*
Rough green snake	*Opheodrys aestivus*
Scarlet kingsnake	*Lampropeltis triangulum elapsoides*
Six-lines racerunner	*Cnemidophorus sexlineatus*
Slender glass lizard	*Ophisaures attenuatus*
Snapping turtle	*Chelydra serpentina*

Appendix 5: NCNERR Species List

Group: Reptiles	
Common Name	**Scientific Name**
Southeastern five-lined skink	*Eumeces inexpectatus*
Southern copperhead	*Agkistrodon contortrix*
Southern hog-nosed snake	*Heterodon simus*
Southern ringneck snake	*Diadophis punctatus punctatus*
Spotted turtle	*Clemmys guttata*
Timber rattlesnake	*Crotalus horridus*
Yellow bellied slider	*Trachemys scripta scripta*
Yellow ratsnake	*E. □olyploi quadrivittata*
Yellow-bellied turtle	*Chrysemys scripta scripta*

Group: Amphibians	
Common Name	**Scientific Name**
Northern cricket frog	*Acris crepitans crepitans*
Southern cricket frog	*Acris gryllus gyrllus*
Mabee's salamander	*Ambystoma mabeei*
Spotted salamander	*Ambystoma muculatum*
Marbled salamander	*Ambystoma opacum*
Mole salamander	*Ambystoma talpoideum*
Eastern tiger salamander	*Ambystoma tigrinum tigrinum*
Two toed amphiuma	*Amphiuma means*
Green salamander	*Aneides aeneus*
Eastern □olyploi toad	*Bufo americanus americanus*
Common toad	*Bufo bufo*
Oak toad	*Bufo quercicus*
Southern toad	*Bufo terrestris*
Fowlers toad	*Bufo woodhousei fowleri*
Southern dusky salamander	*Desmognathus auriculatus*
Spotted dusky salamander	*Desmognathus conanti*
Northern dusky salamander	*Desmognathus fuscus*

Group: Amphibians	
Common Name	**Scientific Name**
Eastern narrow-mouthed toad	*Gastrophryne carolinensis*
Four-toed salamander	*Hemidactylium scutatum*
Gray tree frog	*Hyla chrysoscelis (diploid form)*
Northern spring peeper	*Hyla cinera cinera*
Green treefrog	*Hyla cinerea*
Northern cricket frog	*Hyla crucifer crucifer*
Pine woods tree frog	*Hyla femoralis*
Green tree frog	*Hyla gratiosa*
Squirell tree frog	*Hyla squirella*
Gray tree frog	*Hyla versicolor (□olyploidy form)*
Little grass frog	*Limnaoedus ocularis*
Broken-striped newt	*N. v. dorsalis*
Dwarf waterdog	*Necturus punctatus*
Red-spotted newt	*Notophthalmus viridescens viridescens*
Atlantic coastal slimy salamander	*Plethodon chlorobryonis*
Eastern red-backed salamander	*Plethodon cinereus*
Slimy salamander	*Plethodone glutinosus glutinous*
Northern spring peeper	*Pseudacris crucifer crucifer*
Brimley's chorus frog	*Pseudarcris brimleyi*
Upland chorus frog	*Pseudarcris trisertiata feriarum*
Eastern mud salamander	*Pseudotriton montanus montanus*
Bullfrog	*Rana catesbeiana*
Greed frog	*Rana clamitans melanota*
Pickerel frog	*Rana palustris*
Southern leopard frog	*Rana sphenocephala utricularia*
Wood frog	*Rana sylvatica*
Southern leopard frog	*Rana utricularia*
Carpenter frog	*Rana virgatipes*
Eastern spadefoot	*Scaphiopus holbrookii*
Greater siren	*Siren lacertina*

Appendix 5: NCNERR Species List

Group: Amphibians	
Common Name	**Scientific Name**
Many-lined salamander	*Stereochilus marginatus*

Group: Fish	
Common Name	**Scientific Name**
Abundant	*Serranus subligarius*
Alewife	*Alosa pseudorharengus*
American eel	*Anguilla rostrata*
American shad	*Alosa sapidissima*
Antenna codlet	*Bregmaceros atlanticus*
Atlantic bonito	*Sarda sarda*
Atlantic bumper	*Chloroscombrus chrysurus*
Atlantic croaker	*Micropogon undulatus*
Atlantic cutlassfish	*Trichiurus lepturus*
Atlantic menhaden	*Brevortia tyrannus*
Atlantic midshipman	*Porichthys plectrodon*
Atlantic needlefish	*Strongylura marina*
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*
Atlantic silverside	*Menidia menidia*
Atlantic spadefish	*Chaetodipterus faber*
Atlantic stingray	*Dasyatis sabina*
Atlantic thread herring	*Opisthonema oglinum*
Banded amberjack	*Seriola zonata*
Banded drum	*Larimus fasciatus*
Banded killifish	*Fundulus diaphanus*
Bank cusk-eel	*Ophidion holbrookii*
Barbfish	*Scorpaena brasiliensis*
Bay anchovy	*Anchoa mitchilli*
Bay whiff	*Citharichthys spilopterus*
Belted sandfish	*Serranus subligarius*
Bighead searobin	*Prionothus tribulus*
Black bullhead	*Ictalurus melas*

Group: Fish	
Common Name	**Scientific Name**
Black crappie	*Pomoxis negromaculatus*
Black drum	*Pogonias cromis*
Black grouper	*Mycteroperca bonaci*
Black seabass	*Centropristis striata*
Blackcheek tonguefish	*Symphurus plagiusa*
Blue angelfish	*Holacanthus bermudensis*
Blue runner	*Caranx crysos*
Blue tang	*Acanthurus coeruleus*
Blueback herring	*Alosa aestivalis*
Blueback herring	*Enneacarthus gloriosus*
Bluefish	*Pomatomus saltatrix*
Bluegill	*Lepomis macrochirus*
Bluntnose stingray	*Dasyatis sayi*
Bowfin	*Amia calva*
Broad flounder	*Paralichthys squamilentus*
Brown bullhead	*Ictalurus nebulosis*
Butterfish	*Peprilus triacanthus*
Carolina hake	*Urophycis earlli*
Carp	*Cyprinus carpio*
Chain pickerel	*Esox niger*
Chain pipefish	*Syngnathus louisianae*
Channel catfish	*Ictalurus punctatus*
Clearnose skate	*Raja eglanteria*
Cocoa damselfish	*Stegastes variablilis*
Conger eel	*Conger oceanicus*
Cownose ray	*Rhinoptera bonasus*
Crested blenny	*Hypleurochilus geminatus*
Crevalle jack	*Caranz hippos*
Croaker	*Micropogon undulatus*
Cubbyu	*Pareques umbrosus*
Darter goby	*Gobionellus boleosoma*
Doctorfish	*Acanthurus chirurgus*
Dog snapper	*Lutjanus jocu*

Appendix 5: NCNERR Species List

Group: Fish	
Common Name	**Scientific Name**
Dusky damselfish	*Stegastes dorsopunicans*
Dusky pipefish	*Syngnathus floridae*
Emerald sleeper	*Erotelis smaragdus*
Feather blenny	*Hypsoblennius hentzi*
Flier	*Centrarchus marcopterus*
Florida pompano	*Trachinotus falcatus*
Flying gurnard	*Dactylopterus volitans*
Freshwater goby	*Gobionellus shufeldti*
Frillfin goby	*Bathygobius soporator*
Fringed filefish	*Monacanthus ciliatus*
Fringed flounder	*Etropus crossotus*
Gag	*Mycteroperca bonaci*
Gag	*Mycteroperca microlepis*
Gizzard shad	*Dorosoma cepedianum*
Golden shiner	*Notemigonus crysoleucas*
Gray snapper	*Lutjanus griseus*
Gray triggerfish	*Balistes capriscus*
Great barracuda	*Sphyraena barracuda*
Greater amberjack	*Seriola dumerilli*
Green goby	*Microgobius thalassinus*
Guaguanche	*Sphyraena guachancho*
Gulf flounder	*Paralichthys albigutta*
Gulf kingfish	*Menticirrhus littoralis*
Gulf pipefish	*Syngnathus scovelli*
Halfbeak	*Hyporhamphus unifasciatus*
Hardhead catfish	*Arius felis*
Harvestfish	*Peprilus alepidotus*
Hickory shad	*Alosa mediocris*
Highfin goby	*Gobionellus oceanicus*
Hogchoker	*Trinectes maculatus*
Horse-eyed jack	*Caranx latus*
Inland silverside	*Menidia beryllina*
Inshore lizardfish	*Synodus foetens*

Group: Fish	
Common Name	**Scientific Name**
Irish pompano	*Diapterus auratus*
King mackerel	*Scomberomorus maculatus*
Ladyfish	*Elops saurus*
Lake chubsucker	*Erimzon sucetta*
Lane snapper	*Lutjanus synagris*
Largemouth bass	*Micropterus salmoides*
Leopard searobin	*Prinotus scitulus*
Lined seahorse	*Hippocampus erectus*
Longnose gar	*Lepisosteus osseus*
Longspine porgy	*Stenotomus caprinus*
Lookdown	*Selene vomer*
Lyre goby	*Evorthodus lyricus*
Margintail conger	*Paraconger caudilimbatus*
Marsh killifish	*Fundulus confluentus*
Mosquitofish	*Gambusia affinis*
Mummichog	*Fundulus heteroclitus*
Mutton snapper	*Lutjanus analis*
Naked goby	*Gobiosoma bosc*
Northern kingfish	*Menticirrhus saxatillis*
Northern pipefish	*Syngnathus fuscus*
Northern puffer	*Sphoeroides maculatus*
Northern searobin	*Prionotus*
Northern sennet	*Sphyraena borealis*
Ocellated flounder	*Ancylopsetta quadrocellata*
Offshore tonguefish	*Symphurus civitatium*
Orange filefish	*Aluterus schoepfi*
Oyster toad	*Opsanus tau*
Oyster toadfish	*Opsanus tau*
Painted wrasse	*Halichoeres caudalis*
Palometa	*Trachinotus goodei*
Permit	*Trachinotus falcatus*
Pigfish	*Orthopristis chrysoptera*
Pinfish	*Lagodon rhomboides*

Appendix 5: NCNERR Species List

Group: Fish	
Common Name	**Scientific Name**
Planehead filefish	*Monacanthus hispidus*
Planespotted eel	*Ophichthus ocellatus*
Pumpkinseed fish	*Lepomis gibbosus*
Rainwater killifish	*Lucania parva*
Red drum	*Sciaenops ocellatus*
Red snapper	*Lutjanus campechanus*
Redfin pickerel	*Esox americans*
Rock seabass	*Centropristis philadelphica*
Rough scad	*Trachurus lathami*
Rough silverside	*Membras martinica*
Rough silverside	*Membras martinica*
Round scad	*Decapterus punctatus*
Round scad	*Decapterus punctatus*
Sand perch	*Diplectrum formosum*
Schoolmaster	*Lutjanus apodus*
Scrawled cowfish	*Acanthostracion quadricornis*
Scrawled filefish	*Aluterus scriptus*
Scup	*Stenotomus chrysops*
Seaboard goby	*Gobiosoma ginsburgi*
Seaweed blenny	*Blennius marmoreus*
Seaweed blenny	*Parablennius marmoreus*
Sergeant major	*Abudefduf saxatilis*
Sharksucker	*Echeneis naucrates*
Sharptail goby	*Gobionellus hastatus*
Sheepshead	*Archosargus probatocephalus*
Sheepshead minnow	*Cyprinodont variegatus*
Shrimp eel	*Ophichthus gomesi*
Silver jenny	*Eucinostomus gula*
Silver perch	*Bairdiella chrysura*
Silver seatrout	*Cynoscion nothus*
Silverstripe halfbeak	*Hyporhamphus meeki*
Skillletfish	*Gobiesox strumosus*
Slippery dick	*Halichoeres bivitttus*

Group: Fish	
Common Name	**Scientific Name**
Smooth butterfly ray	*Gymnura micrura*
Smooth dogfish	*Mustelus canis*
Smooth puffer	*Lagocephalus laevigatus*
Snowy grouper	*Epinephelus niveatus*
Southern flounder	*Paralichthys lethostigma*
Southern hake	*Urophucis floridana*
Southern kingfish	*Menticirrhus americanus*
Southern stargazer	*Astroscopus y-graecum*
Southern stingray	*Dasyatis americana*
Spanish mackerel	*Scomberomorus maculatus*
Speckled worm eel	*Myrophis punctatus*
Spiny dogfish	*Squalus acanthias*
Spot	*Leiostomus xanthurus*
Spotfin mojarra	*Eucinostomus argenteus*
Spottail pinfish	*Diplodus holbrooki*
Spotted bass	*Micropterus punctulatus*
Spotted butterflyfish	*Chaetodon ocellatus*
Spotted hake	*Urophycis regia*
Spotted scorpionfish	*Scorpaena plumieri*
Spotted seatrout	*Cynoscion nebulosus*
Spotted whiff	*Citharichthys macrops*
Star drum	*Stellifer lanceolatus*
Stiped bass	*Morone saxatilis*
Striped anchovy	*Anchoa hepsetus*
Striped bass	*Morone saxatilis*
Striped blenny	*Chasmodes basquianus*
Striped burrfish	*Chilomycterus schoepfi*
Striped killifish	*Fundulus majalis*
Striped mullet	*Mugil cephalus*
Striped searobin	*Prionotus evolans*
Summer flounder	*Paralichthys dentatus*
Tadpole madtom	*Noturus gyrinus*
Tautog	*Tautoga onitis*

Appendix 5: NCNERR Species List

Group: Fish	
Common Name	**Scientific Name**
Threadfin shad	*Dorosoma petenense*
Tidewater silverside	*Menidia beryllina*
Tomtate	*Haemulon aurolineatum*
Vermilion snapper	*Rhomboplites aurorubens*
Warmouth	*Lepomis gulosus*
Weakfish	*Cynoscion regalis*
White catfish	*Ictalurus catus*
White grunt	*Haemulon plumieri*
White mullet	*Mugil curema*
White perch	*Morone americana*
Whitebone porgy	*Calamus leucosteus*
Whitespotted soapfish	*Rypticus maculatus*
Windowpane	*Scophthalmus aquosus*
Yellow bullhead	*Ictalurus natalis*
Yellow jack	*Caranx bartholomaei*
Yellow perch	*Perca flavescens*

Group: Invertabrates	
Common Name	**Scientific Name**
Acorn worm	*Balanoglossus auranticus*
Alternate bittium	*Diastoma alternatum*
Alternate tellin	*Tellina alternata*
Amethyst gem clam	*Gemma gemma*
Antillean lima	*Lima pellucida*
Arrow shrimp	*Tozeuma carolinense*
Atlantic abra	*Abra aequalis*
Atlantic auger	*Terebra dislocata*
Atlantic jackknife clam	*Ensis directus*
Atlantic jingle	*Anomia simplex*
Atlantic moon snail	*Polinices duplicatus*

Group: Invertabrates	
Common Name	**Scientific Name**
Atlantic oyster drill	*Urosalpinx cinerea*
Atlantic ribbed mussel	*Modiolus demissus*
Atlantic slipper shell	*Credpidula fornicata*
Atlantic surf clam	*Spisula solidissima*
Atlantic wing oyster	*Pteria colymbus*
Baby's ear	*Sinum perspectivum*
Banded hermit crab	*Pagurus annulipes*
Banded tulip	*Fasciolaria hunteria*
Barnacles on crabs and *Limulus*	*Balanus amphitrite*
Barnacles on crabs and *Limulus*	*Chelonibia patula*
Bay scallop	*Argopecten irradians*
Beach hopper	*Orchestia platensis*
Beach hopper	*Talorchestia longicornis*
Big claw snapping shrimp	*Alpheus heterochaelis*
Black marsh crab	*Sesarma reticulata*
Blood ark	*Anadara ovalis*
Blood worm	*Glycera americana*
Blood worm	*Glycera dibranchiata*
Blue crab	*Callinectes sapidus*
Boring sponge	*Cliona celata*
Brackish water mud crab	*Rhithropanopeus harrisii*
Brief squid	*Lolliguncula brevis*
Brown grooved shrimp	*Penaeus aztecus*
Brown moss animal	*Bugula neritina*
Bryozoan on *Pinnixa chaetopterana*	*Triticella elongata*
Carolina marsh clam	*Polymesoda caroliniana*
Cayenne keyhole limpet	*Diodora cayenensis*
Channeled barrel-bubble	*Retusa canaliculata*

Appendix 5: NCNERR Species List

Group: Invertabrates	
Common Name	**Scientific Name**
Channeled whelk	*Busycon canaliculatum*
Clam worm	*Nereis pelagica*
Cloak anemone	*Calliactus polypus*
Common awning clam	*Solemya velum*
Common blue mussel	*Mytilus edulis*
Common eastern chiton	*Chaetopleura apiculata*
Common eastern nassa	*Nassarius vibex*
Common mud crab	*Panopeus herbstii*
Common prawn	*Palaemonetes vulgaris*
Common slipper shell	*Crepidula fornicata*
Common starfish	*Asterias forbesi*
Conquina	*Donax parvula*
Convex slipper shell	*Crepidula convexa*
Coquina	*Donax romeri protracta*
Crab in bivalve shells and *Chaetopterus* tubes	*Pinnotheres maculata*
Crab in *Chaetopterus* tubes	*Pinnixa chaetopterana*
Crab on the underside of sand dollar	*Dissodactylus mellitae*
Crested oyster	*Ostrea equestris*
Cross-barned venus	*Chione cancellata*
Cross-hatched lucine	*Divaricella quadrisulcata*
Daisy brittlestar	*Ophiopholis aculeata*
Disk dosinia	*Dosinia discus*
Dragonfly	*Erythrodiplax berenice*
Dwarf hermit crab	*Pagurus longicarpus*
Easter mud nassa	*Ilyanassa obsoleta*
Eastern oyster	*Crassostrea virginica*
Eastern paper bubble	*Haminoea salitaria*
Eel grass shrimp	*Hippolyte pleuracantha*

Group: Invertabrates	
Common Name	**Scientific Name**
Fallen angel wing	*Barnea truncata*
False angel wing	*Petricola pholadiformis*
Feather duster	*Hydroides dianthus*
Feather duster	*Sabella microphthalma*
Feather duster	*Sabellaria vulgaris*
Feather-duster	*Janua brasilensis*
Fern hydroid	*Pennaria tiarella*
Five-hole sand dollar	*Mellita fquinquiesperforata*
Flat clawed hermit crab	*Pagurus pollicaris*
Flatworms in gill books of *Limulus*	*Bdellura candida*
Florida rock shell	*Thais hemostoma floridana*
Friendly crab	*Sesarma cinerea*
Garlic sponge	*Lissodendoryx isodictyalis*
Ghost crab	*Ocypode quadrata*
Ghost shrimp	*Callianassa major*
Giant atlantic cockle	*Dinocardium robustum*
Giant atlantic murex	*Murex fulvescens*
Giant scale worm	*Polydontes lupina*
Giant swallotail	*Papilio cresphontes*
Goose barnacle on gills of *Callinectes*	*Octolasmis mulleri*
Gray pygmy venus	*Chione grus*
Great southern white butterfly	*Ascia monuste phileta*
Greedy dove shell	*Anachis avara*
Green beads	*Perophora viridis*
Green tubed worm	*Loimia viridis*
Gribble	*Limnoria tripunctata*
Hairy brittlestar	*Ophiothrix angulata*

Appendix 5: NCNERR Species List

Group: Invertabrates	
Common Name	**Scientific Name**
Hairy mud crab	*Pilumnus sayi*
Half smooth odostome	*Odostomia seminuda*
Heart urchin	*Moira atropos*
Hermit crab hydroid	*Hydractinia echinata*
Hermit crab sponge	*Xestospongia halichondroides*
High tide barnacle	*Chthamalus fragilis*
Hooked mussel	*Brachiodontes recurvis*
Horseshoe crab	*Limulus polyphemus*
Hydroid on hermit crabs	*Hydractinia echinata*
In *Chaetopterus* tubes	*Polyonyx gibbesi*
In dead tests of *Mellita*	*Thalassema mellita*
Ivory barnacle	*Balanus eburneus*
Jointed worm	*Clymenella mucosa*
Knobbed whelk	*Busycon carica*
Laboratory ribbon worm	*Cerebratulus lacteus*
Laboratory sea cucumber	*Thyone briareus*
Lady crab	*Ovalipes ocellatus*
Lamp shell	*Glottidia pyramidata*
Lancelot	*Branchiostoma caribbean*
Leathery sea squirt	*Styela plicata*
Lettered olive	*Oliva sayana*
Lightning whelk	*Busycon contrarium*
Long-finned squid	*Loligo pealii*
Lug worm	*Arenicola cristata*
Lunar dove shell	*Mitrella lunata*
Mahogany data mussel	*Lithophaga bisulcata*
Mantis shrimp	*Squilla empusa*
Marsh periwinkle	*Littornia irrorata*
Mole crab	*Emerita talpoidea*

Group: Invertabrates	
Common Name	**Scientific Name**
Mud fiddler	*Uca pugnax*
Mussel crab	*Pinnotheres maculatus*
Northern dwarf tellin	*Tellina agilis*
Northern quahog	*Mercenaria mercenaria*
Northern star coral	*Astrangia astreiformis*
Opal worm	*Arabbella iricolor*
Ornate worm	*Amphitrite ornata*
Oyster crab	*Pinnotheres ostreum*
Palamedes Swallowtail butterfly	*Papilio palamedes*
Parchment worm	*Chaetopterus variopedatus*
Pink hearted hydroid	*Tubularia crocea*
Pink sea pork	*Amaroecium pellucidum*
Plumed worm	*Diopatra cuprea*
Plumed worm	*Onuphis magna*
Pollution worm	*Capitella capitata*
Porcelain crab	*Polyonyx gibbesi*
Porcelain crab	*Petrolistes galathinus*
Purple sea urchin	*Arbacia punctulata*
Purple striped barnacle	*Balanus amphitrite*
Purple tube sponge	*Adocia tubifera*
Purplish tagelus	*Tagelus divisus*
Red beard sponge	*Microciona prolifera*
Red-jointed fiddler	*Uca minax*
Rigid pen shell	*Atrina rigida*
Rock anemone	*aiptasis pallida*
Saltmarsh Skipper	*Panoquina panoquin*
Sand dollar crab	*Dissodoctylus mellitae*
Sand dollar sausage worm	*Thalassema mellita*
Sand fiddler	*Uca pugilator*

Appendix 5: NCNERR Species List

Group: Invertabrates	
Common Name	**Scientific Name**
Saw-tooth pen shell	*Atrina serrata*
Scale worm	*Lepidametria commensalis*
Scale worm	*Lepidonotus variablils*
Schorched mussel	*Brachiodontes exustus*
Sculptured top shell	*Calliostoma euglyptum*
Sea grape	*Mogula manhattensis*
Sea hare	*Aplysia willcoxi*
Sea mat	*Membranipora tenuis*
Sea nettle	*Chrysaora quinquecirrha*
Sea pork	*Amaroecium constellatum*
Sea roach	*Lygida exotica*
Sea spider	*Anoplodactylus lentus*
Sea walnut	*Mnemiopsis leidyi*
Sea whip	*Leptogorgia virgulata*
Sea whip barnacle	*Balanus galeatus*
Sheeps wool	*Amathia convoluta*
Shipworm	*Bankia gouldii*
Shipworm	*Teredo navalis*
Short-spined sea urchin	*Lytechinus variegatus*
Single-toothed simnia	*Neosimnia uniplicata*
Slipper shells on *Limulus*	*Crepidula fornicata*
Slipper shells on *Limulus* and hermit crab shells	*Crepidula plana*
Sloppy guts anemone	*Ceriantheopsis americanus*
Smooth barnacle	*Balanus improvisus*
Soft-shell clam	*Mya arenaria*
Southern quahog	*Mercenaria campechiensis*
Speckled crab	*Arenaeus cribrarius*
Spider crab	*Libinia dubia*
Spider crab	*Pelia mutica*

Group: Invertabrates	
Common Name	**Scientific Name**
Spotted shrimp	*Penaeus duorarum*
Staghorn bryozoan	*Schizoporella unicornis*
Stone crab	*Menippe mercenaria*
Stout tagelus	*Tagelus plebeius*
Striped hermit crab	*Clibanarius vittatus*
Striped sea cucumber	*Thyone gemmata*
Sulphur sponge	*Aplysilla sulfurea*
Sun sponge	*Hymeniacidon heliophila*
Sunray venus	*Macrocallista nimbosa*
Tenta macoma	*Macoma tenta*
Thick-lipped drill	*Eupleura caudata*
Tinted cantharus	*Cantharus tinctus*
Transparent shrimp	*Periclimenes longicaudatus*
Transverse ark	*Anadara transversa*
Tree coral	*Oculina arbuscula*
Trumpet worm	*Cistenides gouldii*
Tulip mussel	*Modiolus americanus*
Variable bittium	*Diastoma varium*
Variable olivella	*Olivella mutica*
Variable olivella	*Olivella mutica*
Virginia bittium	*Diastoma virginicum*
War-legs brittlestar	*Ophioderma brevispina*
Waterboatman	*Trichocorixa verticalis*
Wedge-shaped martesia	*Martesia cuneiformis*
White bearded ark	*Barbatia candida*
White sea pork	*Didemnum candidum*
White shrimp	*Penaeus setiferus*
White slipper shell	*Crepidula plana*
Worm sea cucumber	*Leptosynapta inhaerens*

Appendix 5: NCNERR Species List

Group: Plants and Ferns	
Common Name	**Scientific Name**
American beach grass	*Ammophila breviligulata*
American beauty berry	*Callicarpa americana*
American elderberry	*Sambucus canadensis*
American holly	*Ilex opaca*
Arrowhead, awl-leaf	*Sagittaria subulata*
Arrowhead, bulltongue	*Sagittaria falcata*
Asparagus	*Asparagus sp.*
Aster, slender	*Aster tenuifolius*
Bacopa	*Bacopa monnieri*
Bamboo-vine	*Smilax laurifolia*
Beach heath	*Hudsonia tomentosa*
Beach primrose	*Oenothera humifusa*
Beakrush, clustered	*Rhynchospora glomerata*
Beakrush, loosehead	*Rhynchospora chalorocephala*
Bean, wild	*Strophostyles helvola*
Bedstraw, catchweed	*Galium aparine*
Bee-balm	*Monarda punctata*
Beggarticks, smooth	*Bidens laevis*
Bermuda grass	*Cynodon dactylon*
Big cordgrass	*Spartina cynosuroides*
Bitter panicum	*Panicum amarum*
Black cherry	*Prunus serotina*
Black locust	*Robinia pseudo-acacia*
Black medicago	*Lythrum lineare*
Black needle rush	*Juncus roemerianus*
Black needlerush	*Juncos roemerianus*
Black willow	*Salix nigra*
Blackberry, sand	*Rubus cuneifolius*
Blackberry, serrate'leaf	*Rubus argutus*
Blanket flower	*Gallium hispidulum*
Blueberry, black highbush	*Vaccinium atrococcum*
Blueberry, elliott's	*Vaccinium elliotti*
Blue-eyed grass	*Sisyrinchium mucronatum*

Group: Plants and Ferns	
Common Name	**Scientific Name**
Bluegrass, annual	*Poa annua*
Bluestem, little	*Schizachyrium scoparium*
Broomsedge	*Andropogon virginicus*
Buckthorn	*Bumelia lycioides*
Bulrush	*Scirpus robustus*
Bulrush, softstem	*Scirpus validus*
Buttercup	*Ranunculus sp.*
Buttercup, celery-leaf	*Ranunculus sceleratus*
Cactus	*Opuntia compressa*
Camphor weed	*Pluchea purpurascens*
Camphorweed	*Gaillardia pulchella*
Carolina willow	*Salix caroliniana*
Cattail, common	*Typha latifolia*
Cattail, narrow-leaf	*Typha angustifolia*
Cattail, southern	*Typha domingensis*
Cherry, ground	*Physalis visocosa ssp. Maritima*
Chicksaw plum	*Prunus angustifolia*
Chickweed, mouse-ear	*Cerastium vicosum*
Climbing hempweed	*Mikania scandens*
Climbing milkweed	*Cynanchum palustre*
Clover	*Trifolium repens*
Coastal Plain willow, Ward's, swamp	*Salix caroliniana*
Cocklebur	*Xanthium strumarium*
Common reed	*Phragmites communis*
Coral honeysuckle	*Lonicera sempervirens*
Cranesbill, carolina	*Geranium carolinianum*
Creeping cucumber marsh	*Melothria pendula*
Cress, bitter	*Cardamine hairsuta*
Croton	*Croton punctatus*
Cucumber, creeping	*Melothria pendula*
Cudweed, narrow-leaf	*Gnaphalium purpureum var. falcatum*
Cutgrass, rice	*Leersia oryzoides*

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Group: Plants and Ferns	
Common Name	**Scientific Name**
Daisy fleabane	*Erigeron canadensis*
Daisy, false	*Eclipta alba*
Dandelion, dwarf	*Krigia virginica*
Dayflower	*Commelina erecta*
Deertongue	*Dichanthelium clandestinum*
Dewberry	*Rubus trivialis*
Diodia	*Diodia teres*
Dock, water	*Rumex verticillatus*
Dodder	*Suscuta campestris*
Dog fennel	*Eupatorium capillifolium*
Dropwort, water	*Oxypolis rigidior*
Duckweed, greater	*Spirodela polythiza*
Duckweed, minute	*Lemna perpusilla*
Dwarf palmetto	*Sabal minor*
Ebony spleenwort	*Asplenium platyneuron*
Eelgrass	*Zostera marina*
Eelgrass	*Vallisneria americana*
Elephant's foot	*Elephantopus nudatus*
Evening primrose	*Oenothera laciniata*
Feather, parrot	*Myriophyllum brasiliense*
Fescue	*Festuca myuros*
Fetterbush, swamp	*Leucothoe racemosa*
Fimbry, forked	*Fimbristylis dichotoma*
Flatsedge, slender	*Cyperus fillicinus*
Flowering dogwood	*Cornus florida*
Foxtail grass	*Setaria geniculata*
Glasswort	*Salicornia virginica*
Goldenrod, anisescented	*Solidago odora*
Goldentop, slender	*Euthamia tenuifolia*
Grape, pigeon	*Vitis cinerea var. floridana*
Grass, □merican cupscale	*Sacciolepis striata*
Grasswort, carolina	*Lilaeopsis carolinensis*
Grasswort, eastern	*Lilaeopsis chinensis*
Greenbriar, catbriar	*Smilax auriculata*
Greenbrier, cat	*Smilax gluca*
Greenbrier, catrier	*Smilax bona-nox*
Greenbrier, laurel-leaf	*Smilax laurifolia*
Greenvriar, catbriar	*Smilax rotundifolia*
Ground cherry	*Physalia viscose*
Groundsel tree, cotton bush, silverling	*Baccharis halimifolia*
Grounsel, wooly	*Senecio tomentosus*
Harper's sea rocket	*Cakile harperi*
Hedge bindweed	*Calystegia sepium*
Hemlock, poison	*Cicuta maculata*
Hempweed, climbing	*Mikania scandens*
Hercules club, devil's walking stick	*Aralia spinosa*
Hercules's club, toothache tree	*Xanthoxylum clava-herculis*
Honeysuckle, coral	*Lonicera sempervirens*
Horehound, water	*Lycopus virginicus*
Horseweed	*Erigeron Canadensis*
Hyssop, water	*Bacopa monnieri*
Jessamine, yellow	*Gelsemium sempervirens*
Lamb's quarters	*Chenopodium album*
Laurel oak	*Quercus laurifolia*
Lippia	*Limonium nashii*
Little blue stem	*Andropogon scoparius*
Live oak	*Quercus virginiana*
Lobelia, downy	*Lobelia puberula*
Loblolly pine	*Pinus taeda*
Loosestrife	*Lippia nodiflora*
Loosestrife, false	*Ludwigia alternifolia*
Low hop clover	*Trifolium campestre*
Maidencane	*Panicum hemitomom*

Appendix 5: NCNERR Species List

Group: Plants and Ferns	
Common Name	**Scientific Name**
Mallow, seashore	*Kosteletzkya virginica*
Marsh aster	*Aster tenuifolius*
Marsh elder	*Iva frutescens*
Marsh elder	*Iva imbricata*
Marsh fleabane	*Pluchea foetida*
Marsh gerardia	*Agalinis maritime*
Marsh pink	*Sabatia stellaris*
Marsh sedge	*Fibristylis spadicea*
Mascadine grape	*Vitis rotundifolia*
Mexican tea	*Chenopodium ambrosioides*
Milfoil, water	*Myriophyllum exalbescens*
Milfoil, yarrow	*Achillea millifolium*
Monarda, dotted	*Monarda punctata*
Morning glory	*Ipomoea sagittata*
Mudeflower, shade	*Micranthemum umbrosum*
Mudwort, awl-leaf	*Limosella subulata*
Muscadine grape	*Vitis rotundifolia*
Nightshade	*Solanum gracile*
Northern bayberry	*Myrica pensylvanica*
Orach	*Atriplex patula*
Orangegrass	*Hypericum gentianoides*
Panic grass	*Panicum virgatum*
Panicum, fall	*Panicum dichotomiflorum*
Paronychia	*Paroychia riparia*
Partridge pea	*Cassia fasciculare*
Passionflower	*Passiflora lutea*
Pearlwort, trailing	*Sagina decumbens*
Pennywort	*Heterotheca subaxillaris*
Pennywort, false	*Centella asiatica*
Pennywort, floating	*Hydrocotyle ranunculoides*
Pennywort, many-flower	*Hydrocotyle umbellata*
Peppervine	*Ampelopsis arboretum*
Persimmon	*Diospryos virginiana*

Group: Plants and Ferns	
Common Name	**Scientific Name**
Pickerelweed	*Pontederia cordata*
Pigweed	*Amaranthus pumilus*
Pimpernel, water	*Samolus parviflorus*
Pinweed, hairy	*Lechea mucrontha*
Pinweed, Leggett's	*Lechea pulchella*
Pittosporum	*Pittosporum tobira*
Plantain	*Plantago aristata*
Plantain	*Plantago lanceolata*
Plantain, pale seed	*Plantago virginica*
Plumegrass, sugarcane	*Saccharum giganteum*
Poison ivy	*Rus radicans*
Poke	*Phytolacca Americana*
Pondweed, bushy	*Najas flexilis*
Pondweed, clasping-leaf	*Potamogeton perfoliatus*
Pondweed, horned	*Zannichellia palustris*
Pondweed, leafy	*Potamogeton foliosus*
Pondweed, sago	*Potamogeton pectinatus*
Pondweeds	*Najas spp.*
Poor man's pepper	*Lactuca sp.*
Prickly pear cactus	*Opuntia drummondii*
Primrose, evening	*Oenothera humifusa*
Primrose, evening	*Oenothera laciniata*
Privet	*Ligustrum japonicum*
Purple muhly	*Muhlenbergia capillaries*
Purslane, water	*Ludwigia palustris*
Rabbit tobacco	*Gnaphalium obtusifolium*
Ragweed	*Ambrosia artemisiifolia*
Red bay	*Persea borbonia*
Red cedar	*Juniperus virginiana*
Redstem, pink	*Ammania teres*
Rush, leathery	*Juncus coriaceus*
Rush, soft	*Juncus effusus*
Rush, turnflower	*Juncus biflorus*

Appendix 5: NCNERR Species List

Group: Plants and Ferns	
Common Name	**Scientific Name**
Russian thistle	*Salsola kali*
Rye grass	*Elmus virginicus*
Salad, corn	*Valerianella radiata*
Salt cedar, tamarix	*Tamarix gallica*
Salt grass, spike	*Distichlis spicata*
Salt marsh cordgrass	*Spartina alterniflora*
Salt meadow hay	*Spartina patens*
Sand nettle	*Cnidoscolus stimulosus*
Sandmat, seaside	*Chamaesyce polygonifolia*
Sandspur	*Cenchrus tribuloides*
Sawgrass	*Cladium jamaicense*
Sea beach orach	*Atriplex arenaria*
Sea bean, beach pea	*Strophostyles helvola*
Sea blite	*Suaeda linearis*
Sea lavender	*Lepidium virginicum*
Sea lavender	*Limonium carolinianum*
Sea oats	*Uniola paniculata*
Sea ox-eye	*Borrichia frutescens*
Sea pink	*Sabatia stellaris*
Sea purslane	*Portulaca oleracea*
Sea purslane	*Sesuvium portulacastrum*
Sea rocket	*Cakile edentula*
Sea spurge	*Euphorbia polygonifolia*
Seashore mallow	*Kosteletskya virginica*
Seaside elder	*Iva imbricate*
Seaside goldenrod	*Solidago sempervirens*
Sedge, japanese	*Carex kobomugi*
Shadbush, serviceberry	*Amelanchier candensis*
Sheep sorrel	*Rumex acetosella*
Smartweed, dotted	*Polygonum punctatum*
Sorrel, sheep	*Rumex hastatulus*
Sourgrass	*Oxalis dillenii*

Group: Plants and Ferns	
Common Name	**Scientific Name**
Spanish bayonet	*Yucca aloifolia*
Spanish moss	*Tillandsia usneoides*
Spike rush	*Eleocharis parvula*
Spikerush, blunt	*Eleocharis obtusa*
Spikerush, small-fruit	*Elocharis microcarpa*
Spikerush, yellow	*Eleocharis flavescens*
Spring lady's tresses	*Spiranthes vernalis*
Squaw huckleberry	*Vaccinium stamineum*
St. Andrews cross	*Hypericum stragalum*
St. John's wort	*Hypericum hypericoides*
Starwort, water	*Callitriche heterophylla*
Sumac, winged	*Rhus copallina*
Swamp rose	*Rosa palustris*
Swamp tupelo	*Nyssa sylvatica var. biflora*
Sweet bay	*Magnolia virginiana*
Sweet white clover	*Medicago lupulina*
Sweet white clover	*Melilotus alba*
Sweetgum	*Liquidambar styraciflua*
Switchgrass	*Panicum virgatum*
Tea, mexican	*Chenopodium ambrosioides*
Thistle, russian	*Salsola kali*
Thistle, yellow	*Cirsium horridulum*
Thoroughwort	*Eupatorium pilosum*
Threesquare, common	*Scirpus americanus*
Threesquare, olney	*Scirpus olneyi*
Toadflax	*Linaria canadensis*
Toothache tree	*Zanthoxylum clava-herculis*
Tresses, ladies	*Spiranthes vernalis*
Vine, pepper	*Ampelopsis arborea*
Violet, bog white	*Viola lanceolata*
Virginia creeper	*Parthenocissus quinquefolia*
Water oak	*Quercus nigra*
Water pimpernel	*Samolus parviflorus*

Appendix 5: NCNERR Species List

Group: Plants and Ferns	
Common Name	**Scientific Name**
Watercress	*Nasturtium officinale*
Wax myrtle	*Myrica cerifera*
Weed, mermaid	*Proserpinaca palustris*
White mulberry	*Morus alba*
Widgeon grass	*Ruppis maritime*
Wild lettuce	*Hydrocotyle bonariensis*
Wild olive	*Osmanthus americana*
Wild sensitive plant	*Cassia nictitans*
Winged sumac	*Rhus copallina*
Wintergreen, spotted	*Chimaphila maculata*
Yarrow, common	*Achillea millefolium*
Yaupon	*Ilex vomitoria*
Yellow jessamine	*Gelsemium sempervirens*
Yellow-eyed grass	*Xyris difformis*
Yellow-eyed grass	*Xyris jupicai*
Yucca	*Yucca gloriosa*

Appendix 6: Bibliography of Research Conducted in NCNERR

Appendix 6: Bibliography of research conducted in NCNERR

Originally compiled by Lancaster et al. 1999. Additional references have been added since then by NCNERR staff.

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